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AD A114039

MEMORANDUM REPORT ARBRL-MR-03162

EXPERIMENTAL TESTING OF A COMBUSTIBLE CASE FOR THE 155MM HOWITZER

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March 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

UNCLASSIFIED

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Memorandum Report ARBRL-MR- 03162

2. GOVT ACCESSION NO.
AD-A114 039

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
EXPERIMENTAL TESTING OF A COMBUSTIBLE CASE FOR THE 155-mm HOWITZER

5. TYPE OF REPORT & PERIOD COVERED
Memorandum Report
1 Oct 78 - 6 May 80

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
US Army Ballistic Research Laboratory
ATTN: DRDAR-BLI
Aberdeen Proving Ground, MD 21005

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
1L162618AH80

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Armament Research & Development Command
US Army Ballistic Research Laboratory (DRDAR-BL)
Aberdeen Proving Ground, MD. 21005

12. REPORT DATE
March 1982

13. NUMBER OF PAGES
86

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Combustible case
Interior ballistics
Consumable case
Cased Charge

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A limited experimental program was conducted to investigate potential ballistic advantages associated with the use of rigid, combustible cases for high-performance artillery charges. Five candidate ignition systems were evaluated for use with the combustible case. An igniter consisting of a Class 5 black powder snake without a basepad was selected, and thirty-nine test charges were assembled and fired with this ignition system. Cold- and ambient-conditioned test charges exhibited lower ignition delays and pressure-wave levels than did the standard Zone 8 control rounds. Somewhat

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higher pressure-wave levels and maximum chamber pressures, however, were experienced with hot-conditioned test rounds when compared to data obtained firing bagged charges employing the same propellant lot. Case residue was minimal under all conditions.

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I. INTRODUCTION

Bagged charges for large-caliber weapons have presented a variety of problems since their inception[1]. Many of these problems must be associated with the lack of rigidity and dimensional stability associated with the use of a cloth bag as the packaging element. Poor alignment between centercore igniter and the primer spit-hole in the spindle may result, leading to improper ignition, high-amplitude pressure waves, and perhaps excessive chamber pressures and even breechblows. Physical dimensions and configural definition are more difficult to control, reducing the effectiveness of devices such as the Swiss notch and spindle standoff bumps used to provide for proper interface distance between the spindle spit-hole and the basepad. Projectile fall-back, a possibility when firing the gun at high elevation, can pose serious problems when the unseated projectile is rapidly accelerated into the origin of rifling as the chamber is pressurized. The rapid deceleration accompanying the impact may lead to detonation of the high explosive or severe damage to internal components. Conventional bagged charges offer little support in the event of a fallback.

Many of the inherent disadvantages of bagged charges could be overcome by the use of a full-bore, tapered, rigid combustible cartridge case. The problem of poor alignment with respect to the spit-hole would no longer exist, removing the need for a basepad and thereby reducing the possibility of unintended base ignition. Physical dimensions and configurations could be maintained, facilitating the control of propelling charge standoff distances, should standoff be warranted. The added strength and rigidity of the combustible case could also help to control the projectile fall-back problem.

The goal of the present work is to evaluate a few of the potential advantages to be gained through the use of a rigid combustible case, in particular for the 155-mm, M203 (Zone 8) Propelling Charge. Thirty-nine felted nitrocellulose combustible cases were supplied by the Large Caliber Weapon Systems Laboratory (LCWSL) for testing at Aberdeen Proving Ground. Five simplified ignition systems received preliminary investigation prior to selection of one for use with the combustible cases. After a brief charge-weight assessment firing program, firings were conducted using combustible case test charges conditioned to three initial temperatures. Standard 155-mm (Zone 8) Propelling Charges were fired as control rounds, and a comparison of results was made in terms of projectile velocities, maximum chamber pressures, pressure waves, ignition delays, and charge residue.

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[1] *I.W. May and A.W. Horst, "Charge Design Considerations and Their Effect on Pressure Waves in Guns,"* <u>*Interior Ballistics of Guns*</u>*, H. Krier and M. Summerfield, Editors, Progress in Astronautics and Aeronautics, Vol. 66, pp. 197-227, AIAA, New York, NY, 1979.*

II. PAST STUDIES

Several years ago Rocchio et al conducted an investigation[2] at the Ballistic Research Laboratory (BRL) in cooperation with LCWSL, Dover, on a combustible case for large-caliber weapons. Felted nitrocellulose cases, each consisting of a cylindrical body section, two end plates and a centercore tube were supplied by LCWSL, and test fired at Aberdeen Proving Ground. The cases were cast with a slight forward taper to conform to the inner dimensions of the M199 Cannon chamber configuration, and the end plates were sized to fit snugly into the ends of the body section. The two ends had a hole in the center, with inner flanges that fitted tightly into the centercore tube.

A large part of Rocchio's study was devoted to the design of a simplified ignition system, and the results from his investigative work guided the selection of candidate ignition systems employed in the current work.

III. EXPERIMENTAL

A. Ignition Systems

A preliminary evaluation was performed on five candidate ignition systems designed to take advantage of the coaxial alignment of the spit-hole and the center of the base of a rigid full-bore charge and to provide a rapid axial propagation rate for ignition of the propellant. To conserve combustible-case components, experimental screening of ignition-system designs 1, 2, and 3 was performed using full-bore cloth bags manufactured from standard M203 bags by adding tapered wedges of cloth to the sidewalls. Evaluation of Designs 4 and 5 was performed, using actual combustible cases, as a part of the limited charge-weight assessment series.

1. Ignition-System Design 1. A standard M203 central igniter bag or "snake," filled with 113g of Class 1 black powder and loaded into a standard centercore tube, was secured within each of three of the previously modified bags. No basepads were used. Figure 1 depicts the charges as assembled.

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[2] *J.J. Rocchio, C.R. Ruth, I.W. May, K.J. White and I. Nadel, "A Consumable Case for Artillery Systems," 1978 JANNAF Propulsion Meeting, CPIA Publication 293, Vol 5, pp. 521-543, February 1978.*

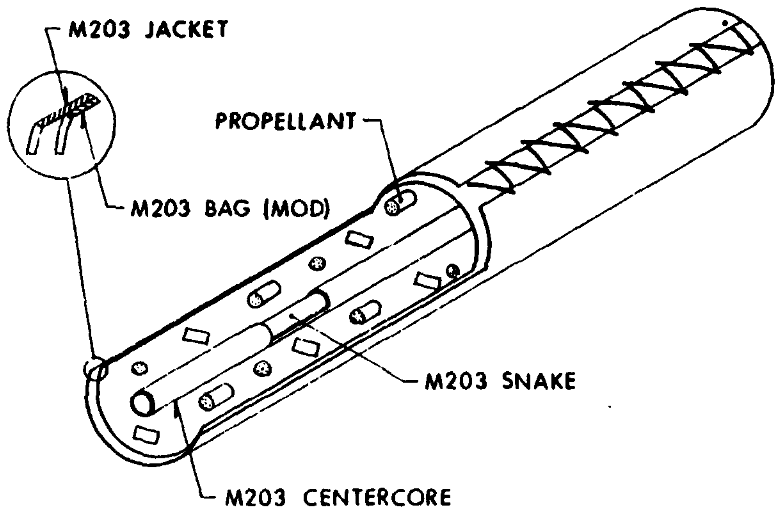

Figure 1. Experimental Ignition System, Design 1

2. Ignition-System Design 2. Shown in Figure 2, this design included the use of three halved centercore-tube sections, secured symmetrically around the inner perimeter of each of three modified M203 bags. The tubes had been sawed in half lengthwise. The purpose was to restore the normal cross-sectional loading density which accompanies the external ullage present when a standard M203 charge is loaded in the M199 Cannon chamber.

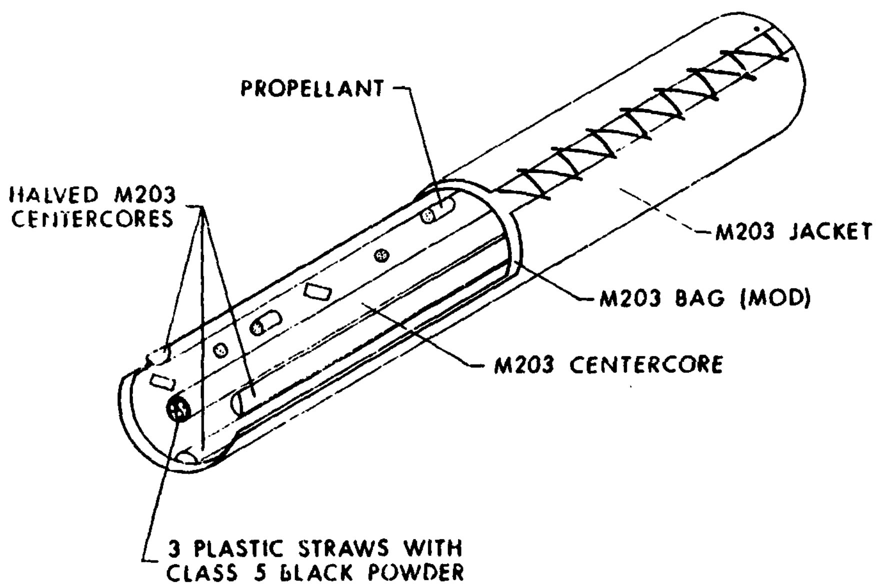

Figure 2. Experimental Ignition System, Design 2

The ignition train consisted of a standard centercore tube and three 724-mm long plastic straws each having an internal diameter (ID) of 8.2 mm and a wall thickness of 0.13 mm. Each straw contained 37.7 g of Class 5 black powder, and the three were tied in a bundle. The bundle of straws was situated inside the centercore so that the ends were flush with the base of the charge, and no basepads were used.

3. Ignition-System Design 3. The ignition system was the same as used in Design 2 with the exception of the centercore. In place of the standard 25.4-mm ID centercore, a 50.8-mm ID centercore tube (modified from a combustible sleeve used in another program) was used to contain the three straws loaded with Class 5 black powder. The three straws were attached to the inner walls at 120° intervals. The straws were bundled together at the base end of the charge to present a single target for the primer gases. Again, no basepads were used. The larger diameter centercore was devised to concentrate all cross-sectional ullage not associated with the interstices of the propellant bed into a single flow port of maximum possible diameter. Figure 3 displays this experimental charge.

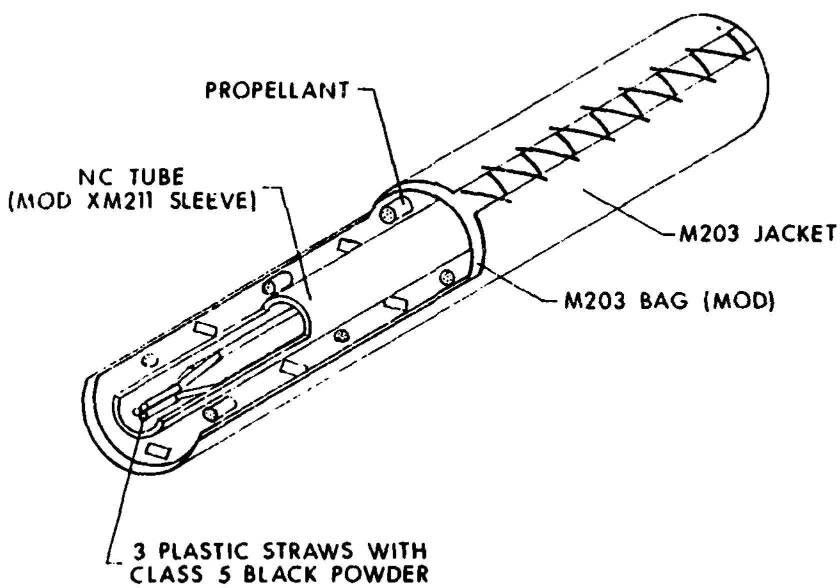

Figure 3. Experimental Ignition System, Design 3

4. Ignition-System Design 4. A fourth igniter design consisted of a hollow snake constructed from an open-mesh, fiberglass screening material. The material selected was 0.25 mm thick, with openings of ∿ 1.0 mm. Each snake was made from 2 pieces of material, 685 mm long and 76 mm wide. The pieces were sewn together longitudinally so that 3 pockets were formed, each 16 mm wide running the length of the material and filled with 37.7 g of Class 5 black powder. The three pockets were separated from each other by a 10-mm wide gap. This assembly was rolled along the longitudinal axis and inserted into a standard centercore tube. After insertion, a wooden dowel 16 mm in diameter was inserted to force the outer wall of the plastic snake against the inner wall of the centercore. This process resulted in an opening throughout the length of the centercore such that a circle circumscribed within the peaks of the loaded pockets had a diameter of 16 mm. A cross section of the completed snake centercore assembly is presented in Figure 4.

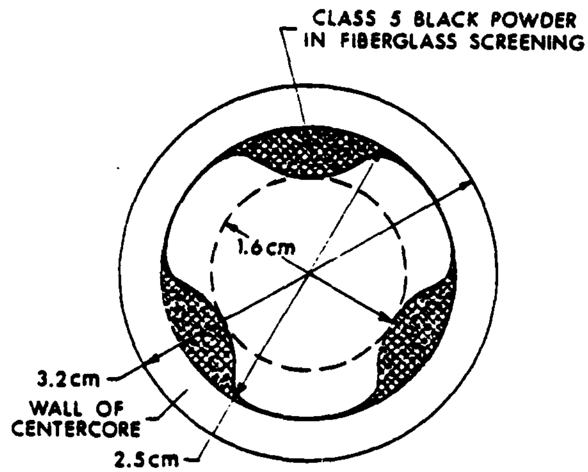

Figure 4. Cross Section of Snake/Centercore Assembly, Design 4

5. Ignition-System Design 5. Design 5 consisted of a standard M203 cloth snake altered in the following manner. Both ties were removed and then reattached so that one was centered 635 mm from the base end perpendicular to the snake, and the other sewn to the forward end, parallel to the longitudinal axis. This placement of the base end ties would assure the proper positioning of the snake inside the centercore tube with respect to the base end of the charge. The placement of the forward ties would force the snake into a straight, in-line position within the centercore and prevent the snake from blocking the flow of hot gases through the tube. 113 g of Class 5 black powder was used with this design.

B. Assembly of Charges

The felted-nitrocellulose combustible cases supplied by LCWSL were identical to those used by Rocchio in his preliminary firings. The composition of the cases is presented in Table 1, and the physical dimensions are listed in Table 2. Figure 5 is a schematic illustration of the combustible case before assembly.

TABLE 1. COMPOSITION OF CASES

Component	Percent by Weight
Nitrocellulose, fibrous	55
Kraft Fiber	9
Acrylic Fiber	25
Resin Binder (Polyvinyl Acetate)	10
Diphenylamine	1

TABLE 2. DIMENSIONS OF COMBUSTIBLE CASES AND COMPONENTS

Case Length	737.0 mm
Case Diameter-forward	158.2 mm
-base	165.6 mm
Wall Thickness	3.2 mm
Base Plate Diameter	159.0 mm
Forward End Plate Diameter	151.0 mm
Centercore Tube-Length	711.0 mm
-OD	32.0 mm
-ID	25.4 mm
Combined Weight (avg. of 30)	1067.5 g (σ = 48.11)

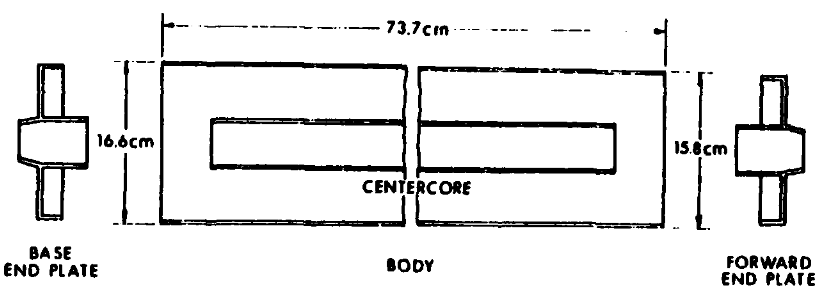

Figure 5. Schematic of a Combustible Case Before Assembly

The first step in the assembly of the charges was the positioning of the snake inside the centercore, followed by fitting of the base of the centercore to the protrusion on the inner face of the base plate. The end of the loaded snake was forced through the hole in the base plate so that the end was flush with the outer surface of the plate. A generous amount of a fast-drying, cellulose-acetate cement was then applied to the joint between the centercore and base plate, and the assembly allowed to dry. Following this, cement was applied to the perimeter of the base-end plate, and the assembly inserted into the base-end (larger ID) of the body of the charge with the centercore positioned in the center of the body.

At this point, the partially assembled charge was ready for loading with propellant. The initial loading showed the interior volume of the case to be considerably greater than the volume required for the propellant. A free space above the surface of the propellant of 50 to 75 cm in length was present. Therefore, to contain the propellant within the volume required for that mass, a retaining device was needed. A solution to the problem was found in the coarse-fibered, hemp material normally used for packing and free-space reduction within the standard metal shipping containers of the M203 Propelling Charges. From this material, 16-mm thick circular pieces were cut to a diameter of ∿ 155 mm with a 32-mm hole in the center. After the charges were loaded, and while still standing on their base ends, the retainers were forced down into the case with the centercore tube protruding through the center hole. With the retainer pressed in place against the propellant, cement was applied to the seams formed by the junction of the retainer and centercore and the perimeter of the retainer and the inner wall of the case.

To further ensure the retainer holding the propellant in place, a spacer consisting of a stiff cardboard tube, 85 mm in diameter, was placed around the centercore tube, one end pressed against the retainer, the other against the forward end plate after its positioning. The length of the cardboard tube was adjusted for each propellant loading. Finally, the forward end plate was cemented into place.

Figure 6 is a photograph of the components of a combustible case charge, with the exception of the cardboard spacer. Figure 7 is a photograph of a fully assembled charge, with the cloth snake slightly protruding from the base end.

C. Test Firings

1. Procedure. All test firings were conducted at the Ballistic Research Laboratory's Sandy Point Firing Facility (R-18), in a 155-mm, M185 Cannon, modified to have an M199 chamber configuration (tapered). Multiple-station pressure-time data, differential pressures, and velocities were recorded by the Ballistic Data Acquisition System (BALDAS)

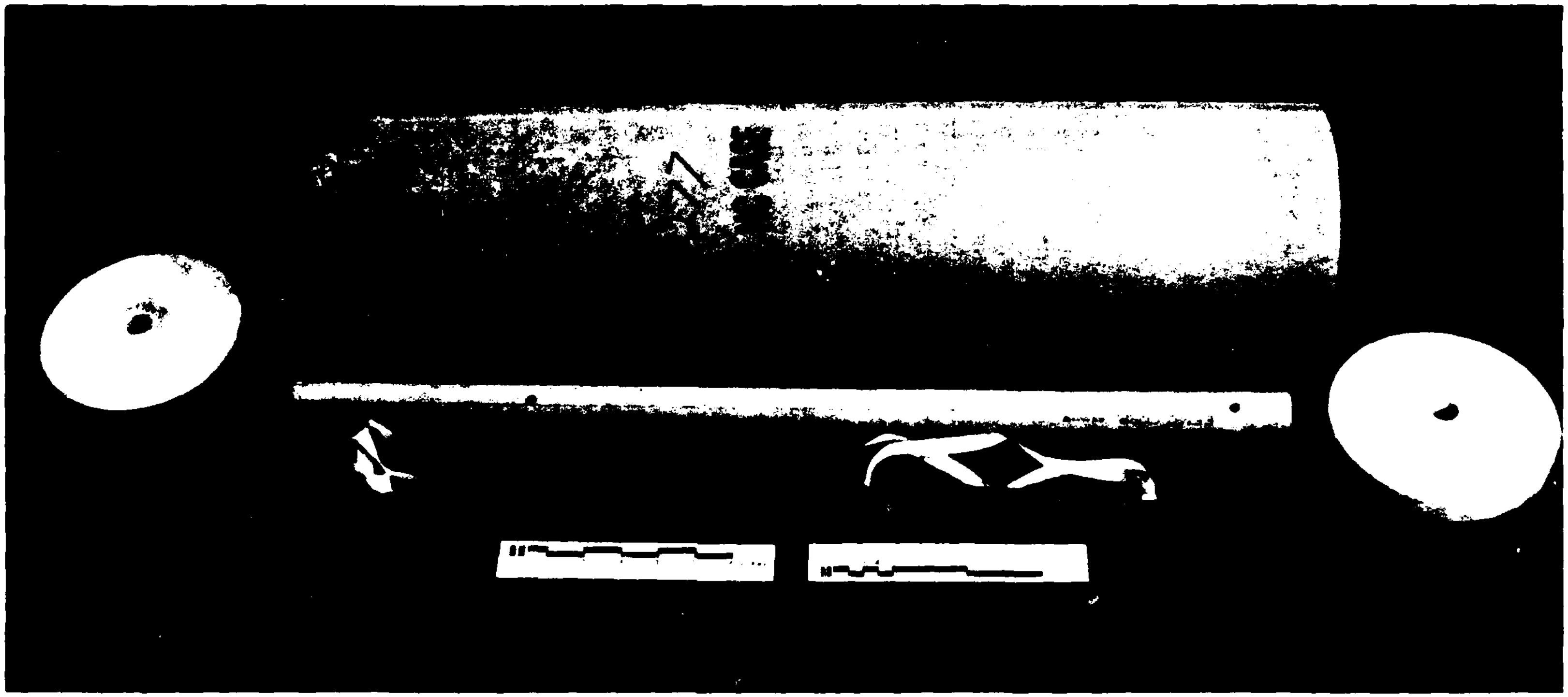

Figure 6. Combustible Case Components

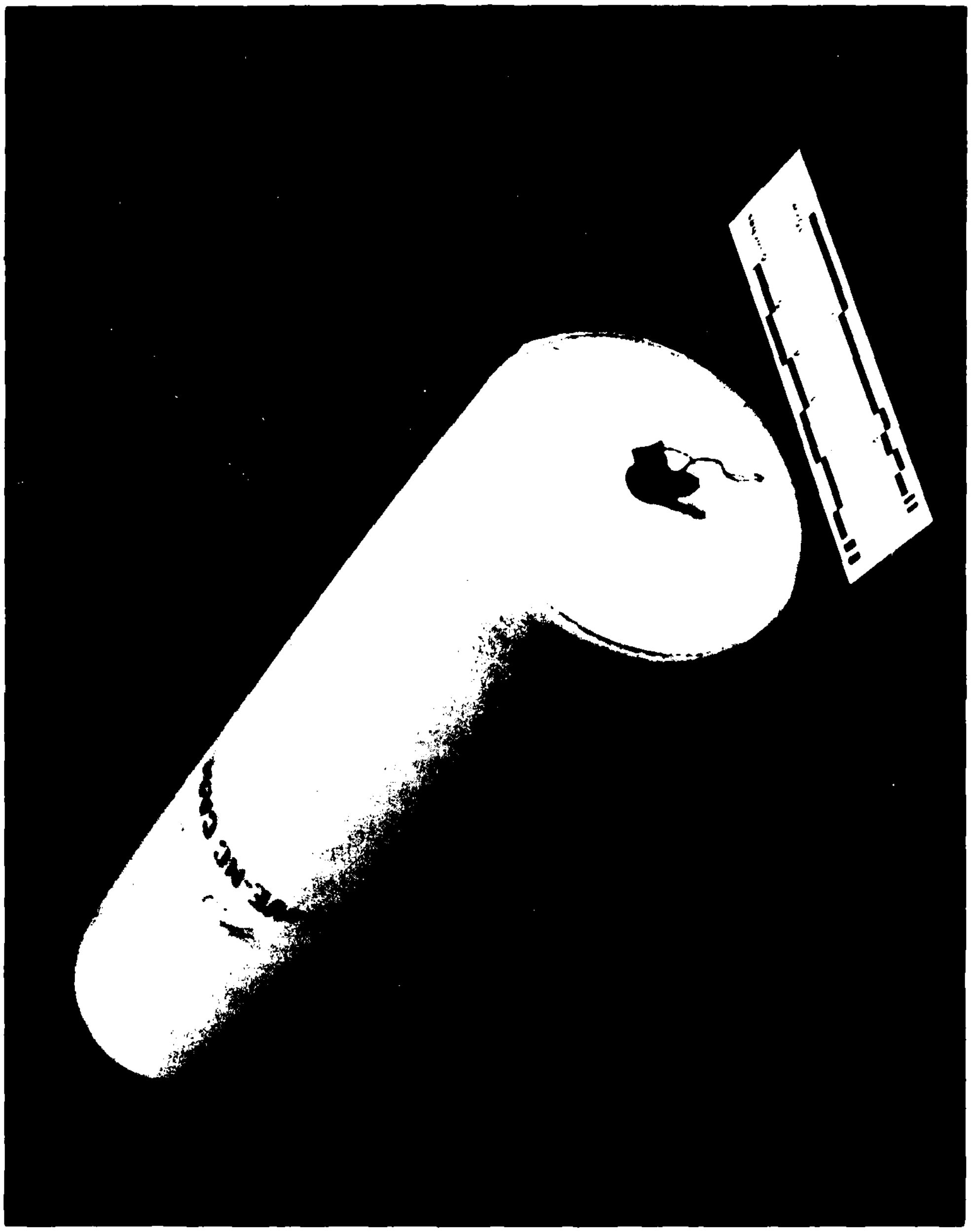

Figure 7. Assembled Charge

under the control of a PDP 11/45 minicomputer. Pressures were measured at six locations within the chamber with Kistler 607C3 piezoelectric transducers: two in the spindle, two at mid-chamber, and two at the projectile base. Those located at positions designated P1, P3 and P5 measured high pressures, while those designated P2, P4 and P6 were used to record events registering pressures less than 20 MPa. Gauge locations are shown in Figure 8. Velocities were measured using solenoid coils spaced approximately 10 meters apart.

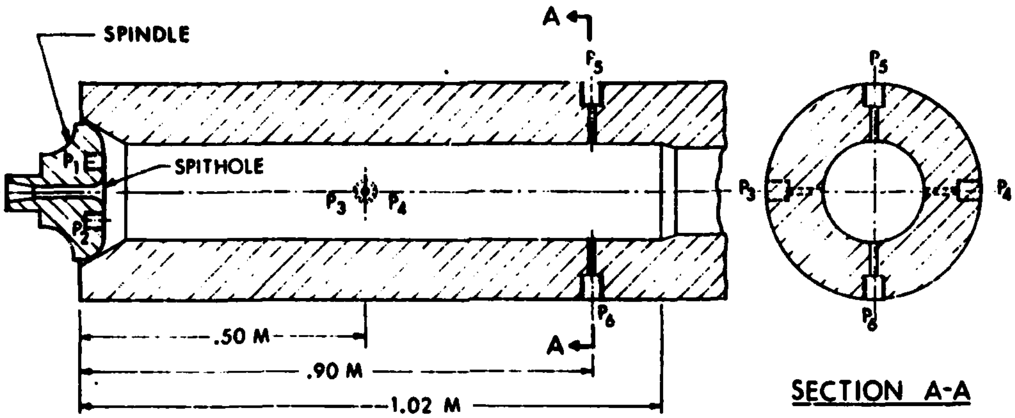

Figure 8. Cannon Chamber with Gauge Locations

Charges were temperature-conditioned for a minimum of twenty-four hours in metal shipping containers before firing. All charges were fired from a zero-standoff distance between the base of the charge and the spindle face. For the probing series, M101 projectiles inert-loaded to 45.36 kg were used, while for the main test firings, inert loading to 43.09 kg was employed. Standard 155-mm (Zone 8), Propelling Charges were used for ballistic-level comparison. M30A1, 7-perforation propellant, Lot RAD77G-069805 was used for all test firings. See Appendix A for Propellant Description Sheet.

2. Experimental Ignition Systems 1, 2 and 3. A separate firing program was conducted to evaluate each of three experimental ignition systems which had been incorporated in M203 charges modified to full-bore configuration. Firing data are tabulated in Appendix B, and a comparison of ignition delays and initial reverse pressure differences ($-\Delta P_i$) is presented in Table 3.

TABLE 3. COMPARISON OF IGNITION DELAYS AND INITIAL REVERSE PRESSURE DIFFERENCES FROM EXPERIMENTAL IGNITION SYSTEMS, DESIGNS 1, 2 AND 3

ID No.		Exp. Ign. System	Chg. Wt. (kg)	Ign. Delay (ms)	$-\Delta P_i$ (MPa)
4		M203 Snake and	10.89	60	3.4
7	#1	Centercore	11.79	46	3.0
8		113g CL-1 BP	11.79	50	2.2
		3 Plastic Straws			
9	#2	113g CL-5 BP	10.89	186	52.2
		M203 Centercore			
10		3 Plastic Straws	10.89	280	6.3
11	#3	113g CL-5 BP	11.79	458	0.0
12		5.08-cm ID Centercore	11.79	348	5.6

3. Experimental Ignition Systems 4 and 5/Charge Weight Assessment.

Eight combustible cases were assembled as described in section 3B, four being equipped with snakes prepared using plastic screening material (Design 4) and four containing modified cloth snakes containing Class 5 black powder (Design 5). Two of each were loaded with 10.89 kg of propellant and two with 11.57 kg of propellant. Results were interpolated to provide a charge weight yielding performance as near as possible to that of standard 155-mm, Zone 8 Propelling Charges (∿ 808 m/s muzzle velocity at ∿ 324 MPa maximum chamber pressure).

Table 4 presents a comparison of ignition delays and initial reverse pressure differences ($-\Delta P_i$) for the eight test charges of this series. Performance data, including muzzle velocities and maximum chamber pressures, for the group are summarized in Table 5. A complete listing of all firing data is tabulated in Appendix C.

TABLE 4. COMPARISON OF IGNITION DELAYS AND INITIAL REVERSE PRESSURE DIFFERENCES ($-\Delta P_i$) OBTAINED WITH EXPERIMENTAL IGNITION SYSTEMS 4 AND 5

ID No.		Exp. Ign. System	Chg. Wt. (kg)	Ign. Delay (ms)	$-\Delta P_i$ (MPa)
19			10.89	21	2
20		Fiber Glass	10.89	16	9
21	#4	113g Cl-5 BP	11.57	19	3
22		M203 Centercore	11.57	16	7
15		M203 Snake	10.89	20	5
16	#5	113g Cl-5 BP	10.89	20	7
17		M203 Centercore	11.57	18	3
18			11.57	17	0

TABLE 5. SUMMARY* OF PERFORMANCE DATA FOR CHARGE-WEIGHT ASSESSMENT SERIES

Charge Weight (kg)	Pmax (MPa)	Vel. (m/s)	Ign. Delay (ms)	$-\Delta P_i$ (MPa)
10.89	320 (7.9)	799 (15.5)	19 (2.2)	6 (3.0)
11.57	358 (3.2)	826 (2.2)	18 (1.3)	3 (2.9)

*Average values from four experimental rounds.
Standard deviations in parentheses.

4. <u>Combustible Case Test Firings</u>. Based on the data presented in Table 5, thirty rigid combustible cases were assembled and loaded with 11.07 kg of M30A1 propellant. In addition, a comparison of the ignition delays and initial reverse pressure differences presented in Table 3 and Table 4 strongly indicated either ignition system 4 or 5 to be acceptable as their performances were essentially equivalent. Design 5 was the easiest to supply and therefore was installed in each of the thirty combustible cases readied for the test firings. Tables 6 and 7 summarize the firing results, while all firing data are tabulated in Appendix C. Computer-generated plots of certain channels (spindle and forward pressures vs. time, pressure-difference vs. time) are included as Appendix D.

TABLE 6. SUMMARY* OF COMBUSTIBLE CASE TEST FIRING DATA

Temp. °C	Chg. Wt. (kg)	Muzzle Vel. (m/s)	P_1 (MPa)	$-\Delta P_i$ (MPa)	Ign. Delay (ms)
+21	11.07	807 (3.5)	301 (4.6)	5 (6.5)	18 (1.8)
-54	11.07	782 (3.8)	294 (7.3)	1 (1.7)	34 (2.4)
+63	11.07	851 (2.6)	373 (9.3)	37 (16.5)	13 (1.9)

*Values are averages of 10-round groups.
Standard deviations in parentheses.

TABLE 7. SUMMARY OF CONTROL ROUND DATA

Temp. °C	Chg. Wt. (kg)	Muzzle Vel. (m/s)	P_1 (MPa)	$-\Delta P_i$ (MPa)	Ign. Delay (ms)
+21	11.70	812* (2.1)	306	4	120
-54	11.70	789**	293	1	143
+63	11.70	860***	397	1	63

* Value is average of 5-round group.
** Value of single round
*** Value is average of 2-round group.
Standard deviation in parentheses.

IV. CONCLUSIONS

A limited experimental program was conducted to investigate potential ballistic advantages associated with the use of rigid, combustible cases for high-performance artillery charges. The particular benefit exploited in this study was the promise of increased charge rigidity and dimensional stability. These features facilitate a reproducible interface between the propelling charge and the chamber in general and between the spindle spit-hole and the propelling charge ignition train in particular, rendering practical centercore igniters that can be initiated directly by primer blast without the aid of a basepad transfer element.

In this effort, a full-bore combustible-cased propelling charge was tested in a 155-mm howitzer employing a centered-spithole spindle. While this configuration maximized the reproducibility of the interface, similar benefits are clearly derivable from the use of a rigid package charge of a reduced diameter with spindles employing dropped spitholes (e.g., M199 Cannon).

Addressing first the igniter screening tests, the occurrence of a large $-\Delta P_i$ with Ignition System Design 2 is not easily explained. Apparently, a localized ignition of the propellant had occurred despite the absence of a basepad, and the three split centercore tubes present just inside the side-wall were unsuccessful in equilibrating pressure gradients so generated.

On the other hand, the large ignition delays accompanying the use of Ignition System Design 3 can be reasonably attributed to the larger free volume inside the special centercore tubes used with this configuration, reducing internal pressures and hence black powder flamespreading and combustion rates.

Ignition delays for combustible case test charges employing the selected, Design 5, ignition system were, however, extremely good, the cold-conditioned charges exhibiting a value less than half that commonly experienced with standard 155-mm, Zone 8 charges. Case residue was acceptable, as well, under all firing conditions. Unfortunately, pressure-wave and maximum chamber pressure levels for hot-conditioned test charges were undesirably high. The mean $-\Delta P_i$ value of 37 MPa was approximately twice as high as the corresponding value for standard M203 Propelling Charges loaded with the same propellant lot and fired from the same tube[3]. Moreover, as shown in Figure 9, the increase in maximum chamber pressure between ambient and hot firings of test charges was nearly twice as great as for standard M203 Charges, again for the same propellant lot and tube[3]. We note that Zone 8 control rounds employing a different lot of propellant but fired along with the combustible-cased rounds yielded even lower pressure-wave levels but the highest hot pressures of all configurations tested.

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[3] *A. W. Horst, J. R. Kelso, J. J. Rocchio and T. C. Minor, "Ballistic Evaluation of 19-Perforation Propellant in the 155-mm Propelling Charge, M203E1," ARBRL-MR-02968, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, October 1979.* (AD A079896)

The increase in pressure waves may be attributable to the full-bore configuration, the missing annular ullage having been previously shown to be extremely important to the reduction of longitudinal pressure gradients in artillery charges[4]. However, the role of charge configuration is only now under serious investigation in respect to its influence on the temperature sensitivity of ballistic performance. Until such time as an explicit, functional representation of packaging materials and other parasitic components is successfully included in multi-dimensional, two-phase flow, interior ballistic models, the charge designer must continue to rely on extensive experimentation for guidance.

ACKNOWLEDGMENT

The authors wish to express their gratitude to Mr. Scott Westley of the Large Caliber Weapon Systems Laboratory, USA ARRADCOM, Dover, New Jersey, for supplying the combustible cases used in this test.

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[4] *A. W. Horst and P. S. Gough, "Modeling Ignition and Flamespread Phenomena in Bagged Artillery Charges," ARBRL-TR-02263, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, September 1980.* (AD A091790)

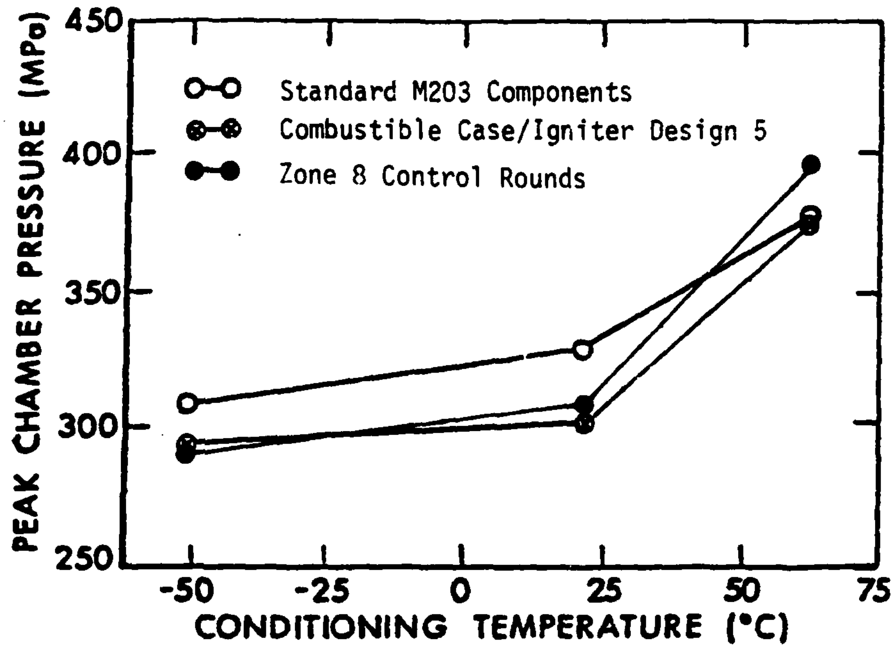

Figure 9. Sensitivity of Maximum Chamber Pressure to Conditioning Temperature

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2. J.J. Rocchio, C.R. Ruth, I.W. May, K.J. White and I. Nadel, "A Consumable Case for Artillery Systems," 1978 JANNAF Propulsion Meeting, CPIA Publication 293, Vol. 5, pp. 521-543, February 1978.

3. A.W. Horst, J.R. Kelso, J.J. Rocchio, and T.C. Minor, "Ballistic Evaluation of 19-Perforation Propellant in the 155-mm Propelling Charge, M203E1," ARBRL-MR-02968, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, October 1979. (AD A079896)

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APPENDIX A

PROPELLANT DESCRIPTION SHEET

PROPELLANT DESCRIPTION SHEET

CORRECTED COPY*

U S Army Lot No. RAD77G-069805 Composition No. M30A1 for Use in Propelling Charge M203, f/155mm How., M198

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 320,975 lbs

Contract No DAAA09-77-C-4007 Date 4-1-77 Specification No MIL-P-48367A

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content		KI Starch (65.5°C)	Stability (134.5°C)
C-35,556; 557; 558; 565; 566; 570; 573; 576; 577; 579	Maximum	12.60 %	Mins	Mins
	Minimum	12.50 %	Mins	Mins
	Average	12.56 %	45+ Mins	30+ Mins
				Explosion

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound ~~NC~~ Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds ACETONE per 100 Pounds Solvent

Percentage Fines to Whole 12

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Days	Hours
		Load Forced Air Dry at Ambient Temperature		
Ambient	140	Increase Temperature 5°F per Hour		
140	140	Hold at Temperature		72

TESTS OF FINISHED PROPELLANT

Propellant Composition: Constituent	Percent Formula	Percent Tolerance	Percent Measured	Stability and Physical Tests	Formula	Actual
Nitrocellulose	28.00	±1.30	27.18	Heat Test S.P. 120°F	NO CC 40'	60'
Nitroglycerin	22.50	±1.00	22.80	No Fumes	- - -	60'
Nitroguanidine	47.00	±1.00	47.54	Form of Propellant, Type I		Cylinder
Ethyl Centralite	1.50	±0.10	1.55	No. of Perforations		7
Potassium Sulfate	1.00	±0.30	0.93			
TOTAL	100.00		100.00			
Graphite Glaze (added)	0.15	Max.	0.08			
Total Volatiles	0.50	Max.	0.33			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD77G-069805	+90	96.51	99.74 %
	RAD77G-069805	-40	92.58	98.16 %
Standard	RAD-E-14		100.00%	100.00%
Remarks				

FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 700 CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions: Spec.	Actual
Length (L)		0.949	0.9481	6.25 Max.	1.08
Diameter (D)		0.470	0.4173	3.125 Max.	1.28
Perf. Dia (d)		0.039	0.0338		
WEB					
Inner		0.0930	0.0793		
Outer		0.0845	0.0806		
Average		0.0888	0.0800		
Web Difference/Std Dev in % of Web Average	15 Max.		2		
L/D	2.10 to 2.50		2.27		
D/d	5.0 to 15		12.4		

DATES	
Packed	7-20-77
Sampled	7-20-77
Test Finished	7-27-77
Offered	8-18-77
Description Sheets Forwarded	8-23-77

Type of Packing Container FIBER DRUMS PER MIL-STD-652C WITH NOTICE 1

Remarks This is the first propellant lot using toluene as an alcohol denaturant.

*Issued to replace description sheet dated 8-10-77 to add statement concerning type of alcohol denaturant used.

THIS LOT MEETS ALL THE CHEMICAL AND PHYSICAL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

Contractor's Representative H. C. Dickinson H.C. Dickinson

Government Quality Assurance Representative JAMES E. BLAND James E Bland

(Orig. 7/76)

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APPENDIX B

TABULATION OF IGNITION SYSTEM FIRING DATA

APPENDIX B

TABULATION OF FIRING DATA-EXPERIMENTAL IGNITION SYSTEMS NO. 1, 2 AND 3

IDENT. NO.	IGNITION SYSTEM	T (°C)	CHG. WT. (kg)	CHG. DIMENSIONS Length (cm)	Diameter (cm) Fwd	Diameter (cm) Mid	Diameter (cm) Base	PROJ. WT. (kg)	SO (cm)	VELOCITY (m/s)	MAX. CHAMBER PRES. (MPa) P_1	MAX. CHAMBER PRES. (MPa) P_5	IGN. DELAY (ms)	$-\Delta P_i$ (MPa)
	Design No. 1													
4	Std. M203 Snake		10.89	60.3	15.4	16.0	16.2	43.5	0	775	278	255	60	3.4
7	113 g Class 1 BP	25	11.79	68.6	15.4	15.8	16.0	43.6	0	825	331	303	46	3.0
8	M203 Centercore		11.79	68.6	15.0	16.0	16.0	43.6	0	826	329	304	50	2.2
	No Basepad													
	Design No. 2													
	3 Plastic Straws													
9	113 g Class 5 BP	25	10.89	68.6	15.4	15.6	16.0	43.5	0	792	300	277	186	52.2
	M203 Centercore													
	No Basepad													
	Design No. 3													
10	3 Plastic Straws		10.89	66.0	15.0	15.4	15.8	43.5	0	761	276	253	280	6.3
11	113 g Class 5 BP	25	11.79	71.1	15.4	15.8	16.2	43.4	0	829	327	301	458	0
12	50-mm Diameter		11.79	71.1	15.0	15.4	15.8	43.5	0	823	320	296	348	5.6
	Centercore													
	No Basepad													

APPENDIX C

TABULATION OF FIRING DATA

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APPENDIX C
TABULATION OF FIRING DATA-COMBUSTIBLE CASES

IDENT. NO.	T (°C)	CHG. WT. (kg)	PROJ. WT. (kg)	SEATING (cm)	VELOCITY (m/s)	MAXIMUM CHAMBER PRESSURE (MPa) P_1	P_3	P_5	IGN. DELAY (ms)	$-\Delta P_i (P_1-P_5)$ (MPa)
15	+20	10.89	45.36	90.0	822	322	Λ	300	20	5
16	"	10.89	"	90.3	796	328	316	303	20	7
19(R)	"	10.89	"	90.3	791	320	310	300	21	2
20	"	10.89	"	90.1	788	309	301	292	16	9
				(Avg.)	799	320	309	299	19	6
				(Std. Dev.)	(15.5)	(7.9)	(7.6)	(4.7)	(2.2)	(3.0)
17	+20	11.57	45.36	90.1	827	361	347	333	18	3
18	"	11.57	"	90.1	829	361	348	334	17	0
21	"	11.57	"	90.3	824	355	342	329	19	3
22	"	11.57	"	90.1	825	356	344	331	16	7
				(Avg.)	826	358	345	332	18	3
				(Std. Dev.)	(2.2)	(3.2)	(2.8)	(2.2)	(1.3)	(2.9)
26	+20	11.07	43.09	90.5	804	298	308	280	19	0
27	"	"	"	90.4	811	307	316	286	15	6
28	"	"	"	90.5	811	305	300	286	16	4
29	"	"	"	90.5	804	297	292	278	21	4
30	"	"	"	90.7	802	296	291	277	17	0
33	"	"	"	90.5	808	304	299	282	17	11
34	"	"	"	90.4	802	294	288	278	18	20
35	"	"	"	90.4	810	306	301	287	17	0
36	"	"	"	90.5	806	302	296	284	16	0
39	"	"	"	90.6	807	298	293	281	19	1
				(Avg.)	807	301	298	282	18	5
				(Std. Dev.)	(3.5)	(4.6)	(8.5)	(3.7)	(1.8)	(6.5)

APPENDIX C
TABULATION OF CONTROL ROUND DATA

IDENT. NO.	T (°C)	CHARGE	PROJ. WT. (kg)	SEATING (cm)	VELOCITY (m/s)	MAXIMUM CHAMBER PRESSURE (MPa) P_1	P_3	P_5	IGN. DELAY (ms)	$-\Delta P_i (P_1-P_5)$ (MPa)
25	+20	XM123E2*	43.09	90.4	811	302	311	283	113	0
32	"	"	"	90.6	812	302	297	285	120	1
42	"	"	"	90.6	815	309	306	292	114	0
55	"	"	"	90.5	814	311	307	293	128	0
64	"	"	"	90.6	810	305	301	286	127	1
				(Avg.)	812	306	304	288	120	.4
				(Std. Dev.)	(2.1)	(4.1)	(5.5)	(4.4)	(7.0)	(0.5)
43	-54	"	43.09	90.5	789	293	289	276	143	1
56	+63	"	43.09	90.5	862	398	403	386	53	0
65	"	"	"	90.5	857	396	395	381	72	2
				(Avg.)	860	397	399	384	63	1
				(Std. Dev.)	(3.5)	(1.4)	(5.7)	(3.5)	(13.4)	(1.4)

* Lot IND 124-74
All charges fired from a 1" stand off

APPENDIX C
TABULATION OF FIRING DATA-COMBUSTIBLE CASES

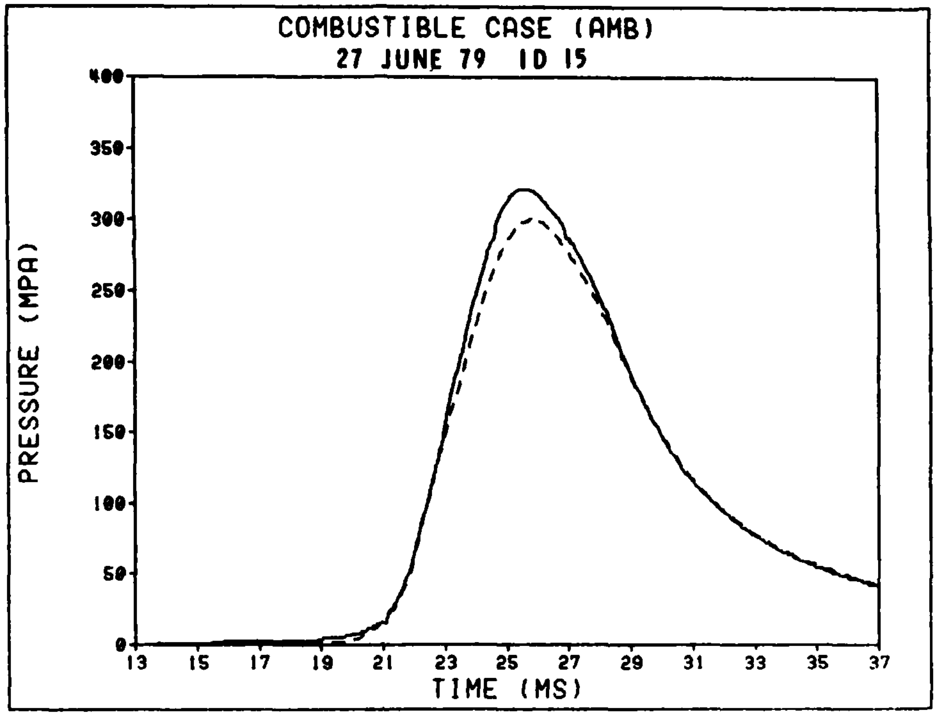
IDENT. NO.	T (°C)	CHG. WT. (kg)	PROJ. WT. (kg)	SEATING (cm)	VELOCITY (m/s)	MAXIMUM CHAMBER PRESSURE (MPa) P_1	P_3	P_5	IGN. DELAY (ms)	$-\Delta P_i(P_1-P_5)$ (MPa)
44	-54	11.07	43.09	90.5	784	297	292	280	✚	0
45	"	"	"	90.5	785	303	298	282	36	5
46	"	"	"	90.5	784	295	292	276	35	1
47	"	"	"	90.4	788	304	301	285	37	0
48	"	"	"	90.6	780	293	288	276	34	0
49	"	"	"	90.6	775	280	278	266	35	3
50	"	"	"	90.4	780	289	288	272	34	0
51	"	"	"	90.5	779	287	284	269	30	1
52	"	"	"	90.5	785	298	296	282	30	0
53*	"	"	"	90.5	781	294	⊙	278	33	2
				(Avg.)	782	294	291	277	34	1
				(Std. Dev.)	(3.8)	(7.3)	(7.2)	(6.1)	(2.4)	(1.7)
57	+63	11.07	43.09	90.5	849	369	361	339	13	39
58	"	"	"	90.6	847	355	350	336	18	6
59	"	"	"	90.5	851	364	356	339	13	25
66	"	"	"	90.6	850	386	373	348	13	71
67	"	"	"	90.5	849	370	358	337	11	37
68	"	"	"	90.7	856	382	369	346	14	49
69	"	"	"	90.5	850	374	362	340	13	38
70	"	"	"	90.7	852	374	360	339	12	33
71	"	"	"	90.6	850	370	355	337	13	32
72	"	"	"	90.5	854	382	365	344	12	39
				(Avg.)	851	373	361	341	13	37
				(Std. Dev.)	(2.6)	(9.3)	(6.8)	(4.1)	(1.9)	(16.5)

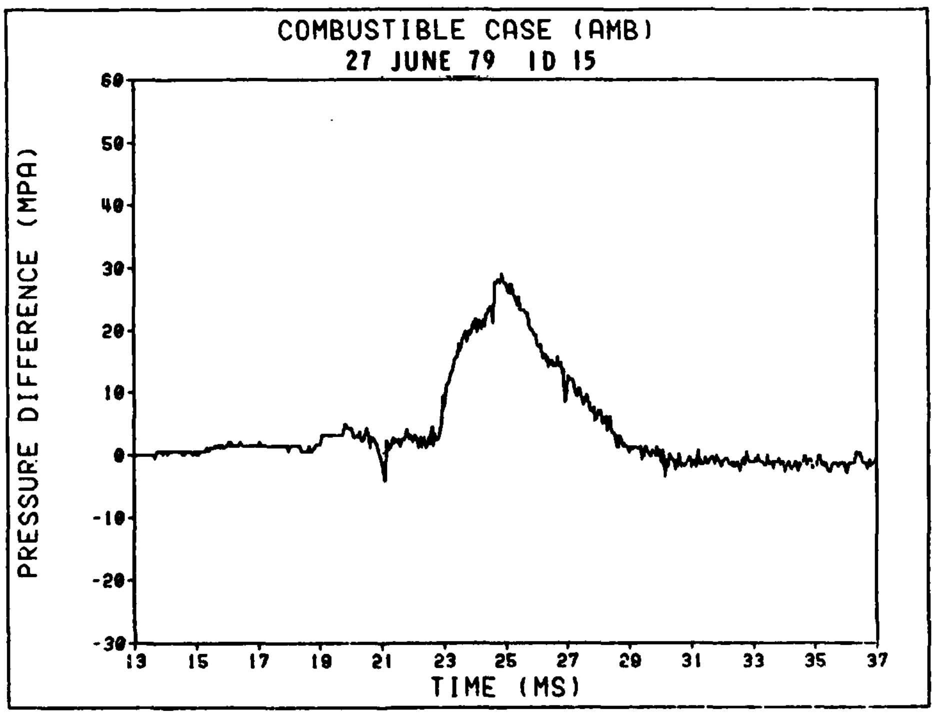
(R) Minor residue
Δ Data not reduced
* Charge knocked over during cold conditioning
⊙ Bad gauge calibration
✚ Missed window

APPENDIX D

PLOTS OF PRESSURE (SPINDLE & FORWARD) AND

PRESSURE-DIFFERENCE VERSUS TIME





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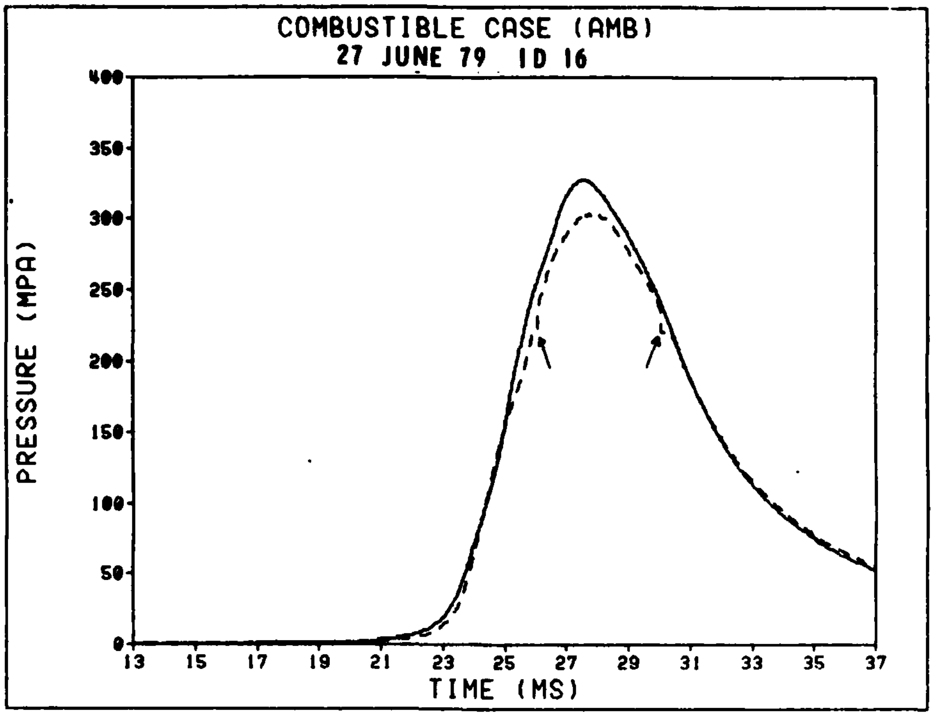
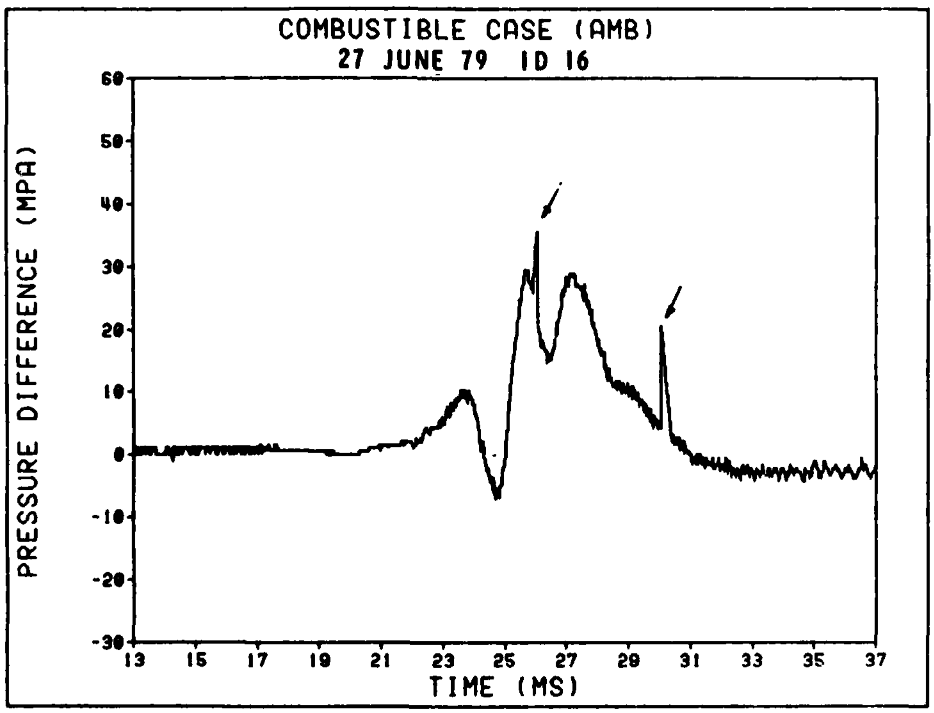
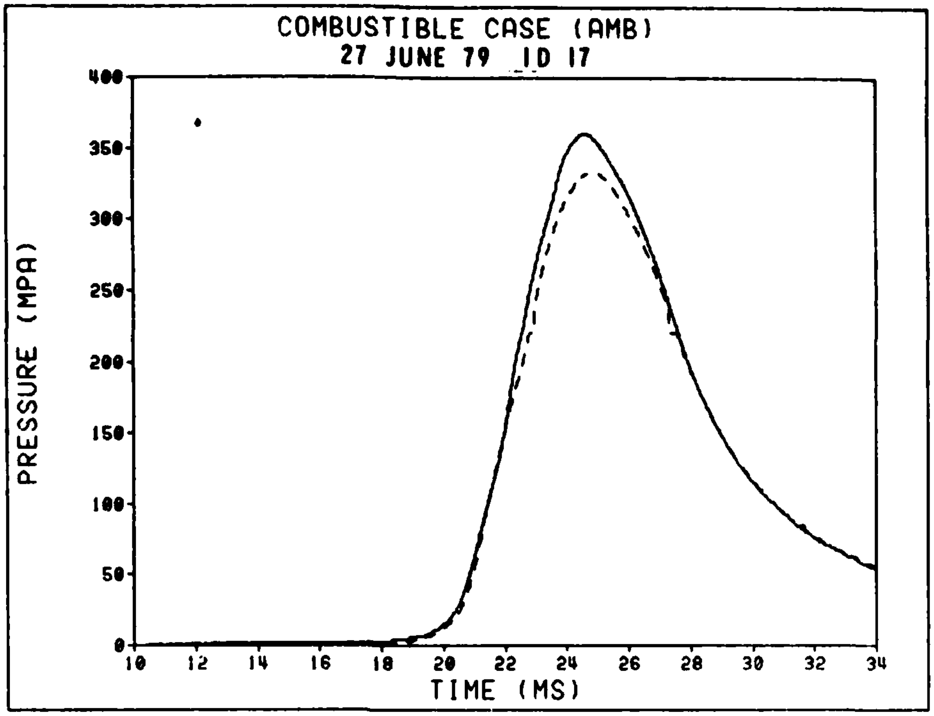




Note: Discontinuities noted in this figure are a result of failure of the analog-to-digital data converter at the time of acquisition and do not reflect physical changes in pressure. Similar discontinuities are present in subsequent figures.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27 JUNE 79 ID 17
PRESSURE (MPA)
TIME (MS)
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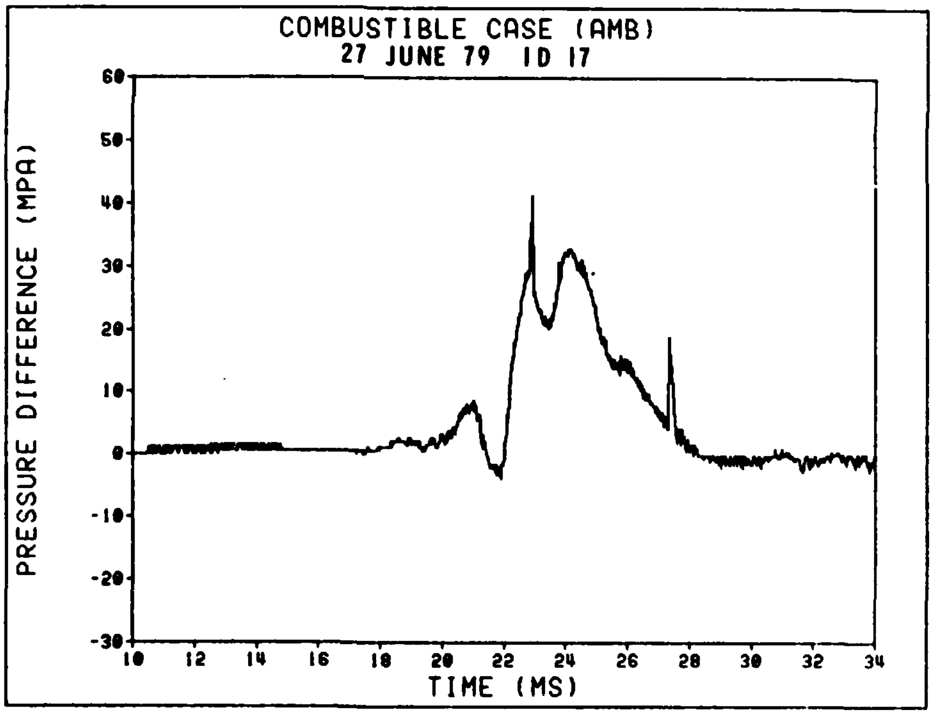
30
32
34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PRESSURE DIFFERENCE (MPA)
TIME (MS)
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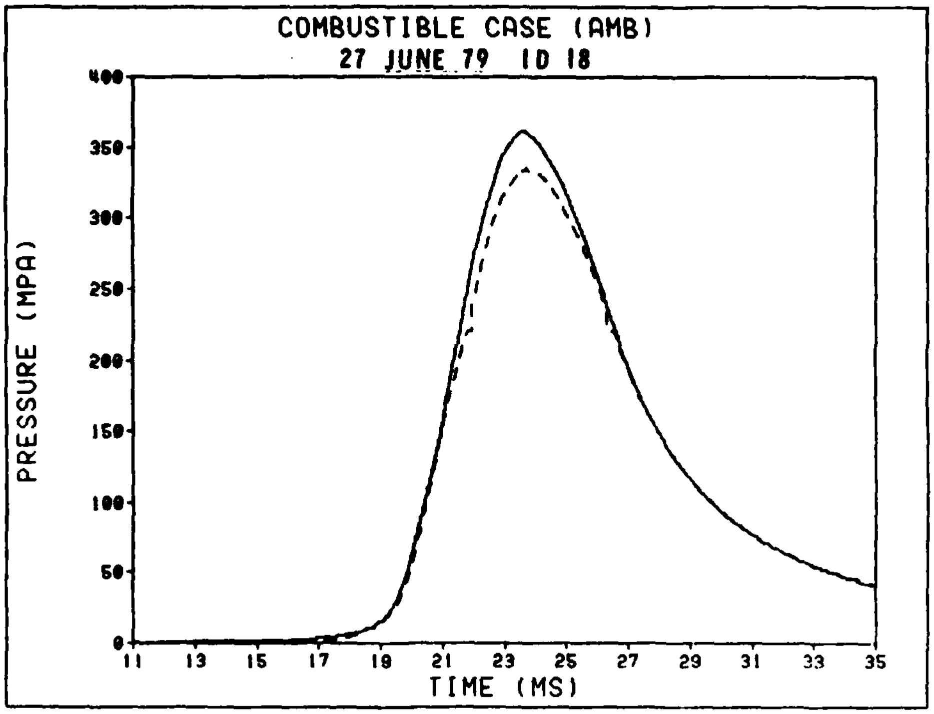
32
34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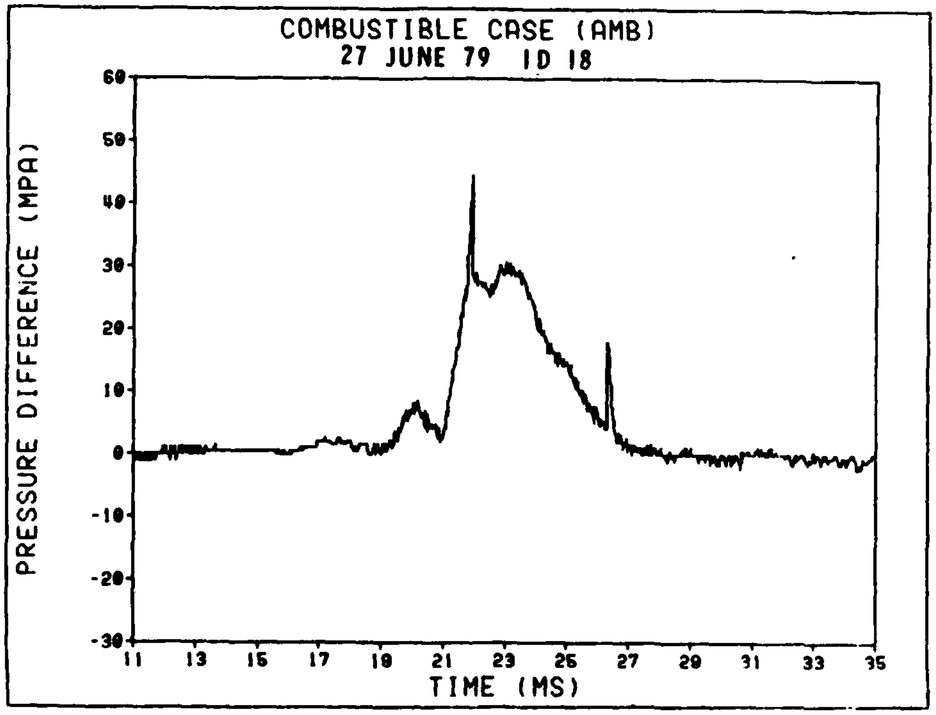
PRESSURE (MPA)
TIME (MS)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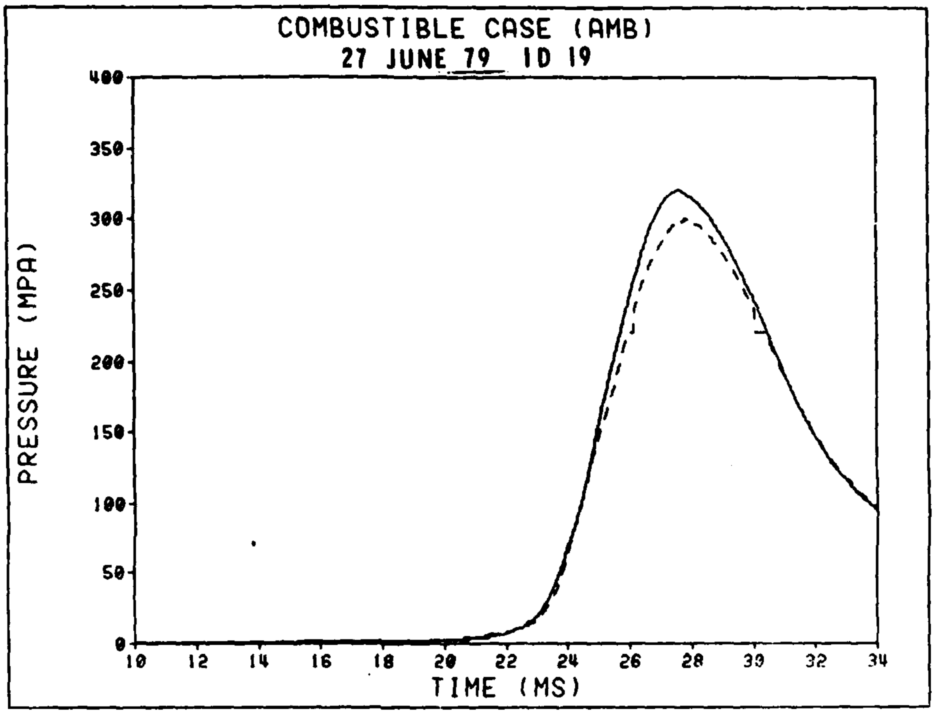
PRESSURE DIFFERENCE (MPA)
TIME (MS)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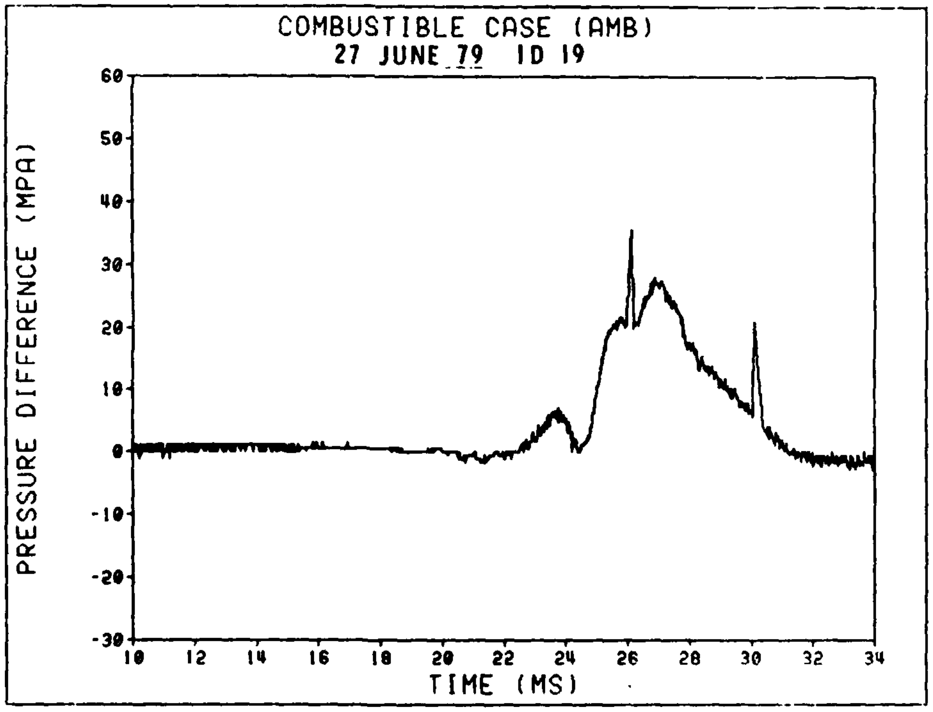
TIME (MS)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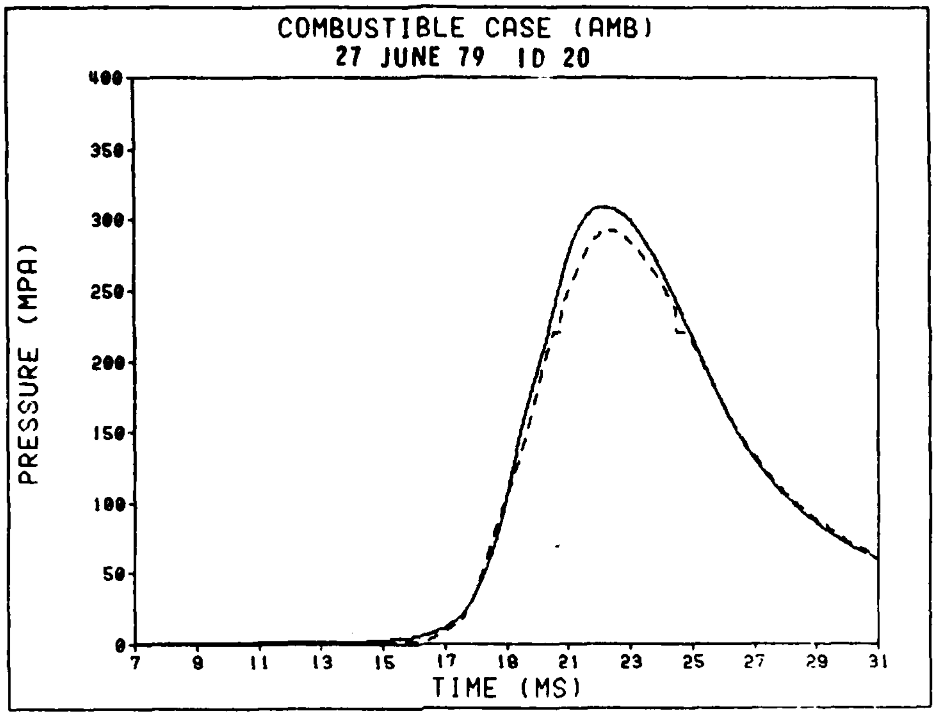
TIME (MS)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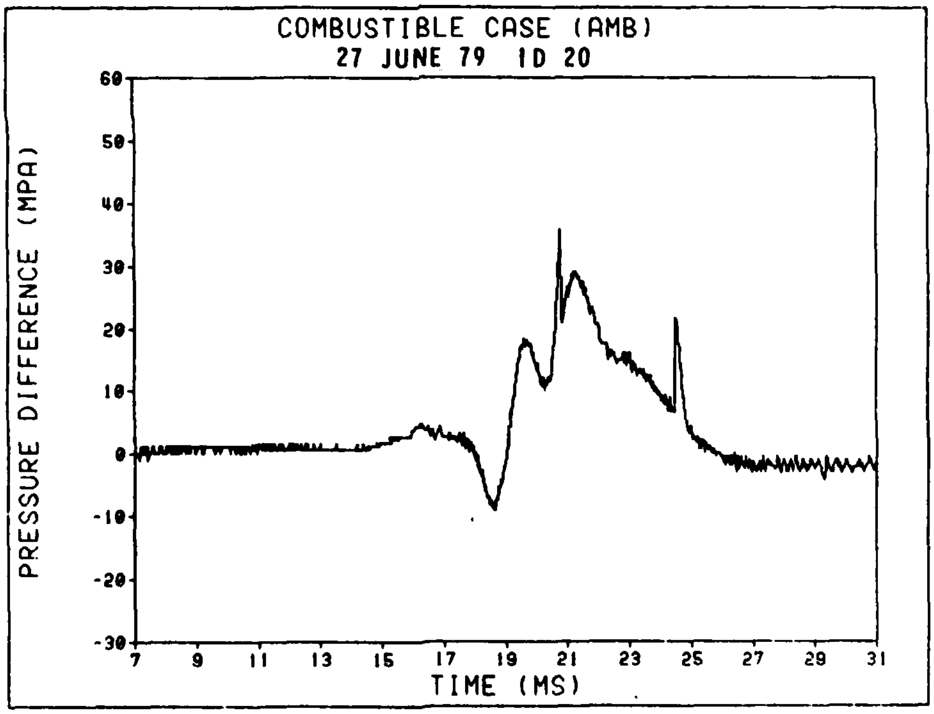
TIME (MS)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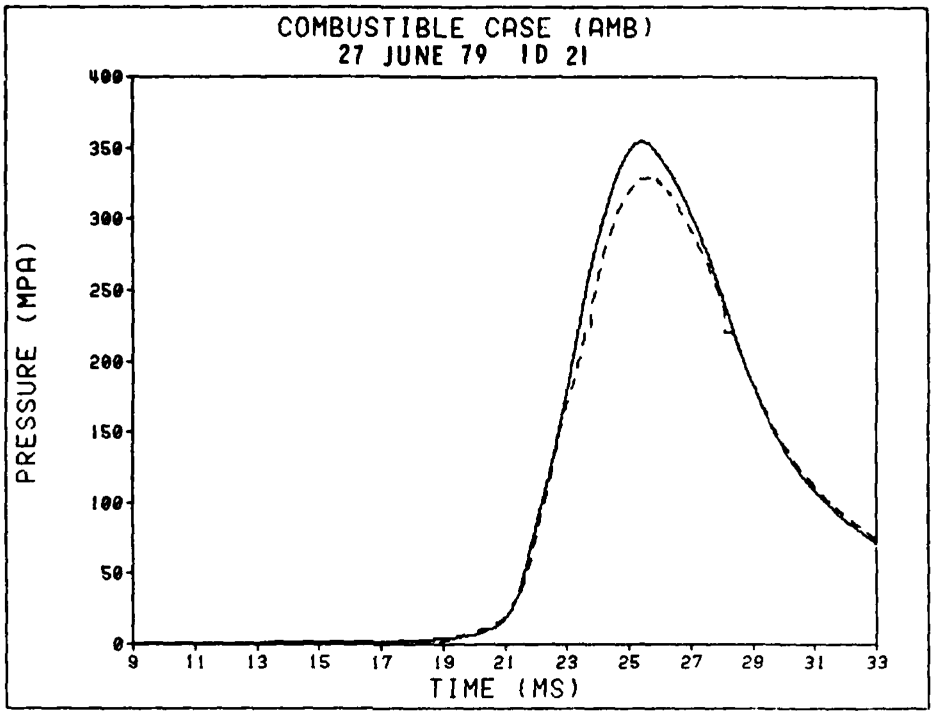
TIME (MS)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PRESSURE (MPA)
TIME (MS)
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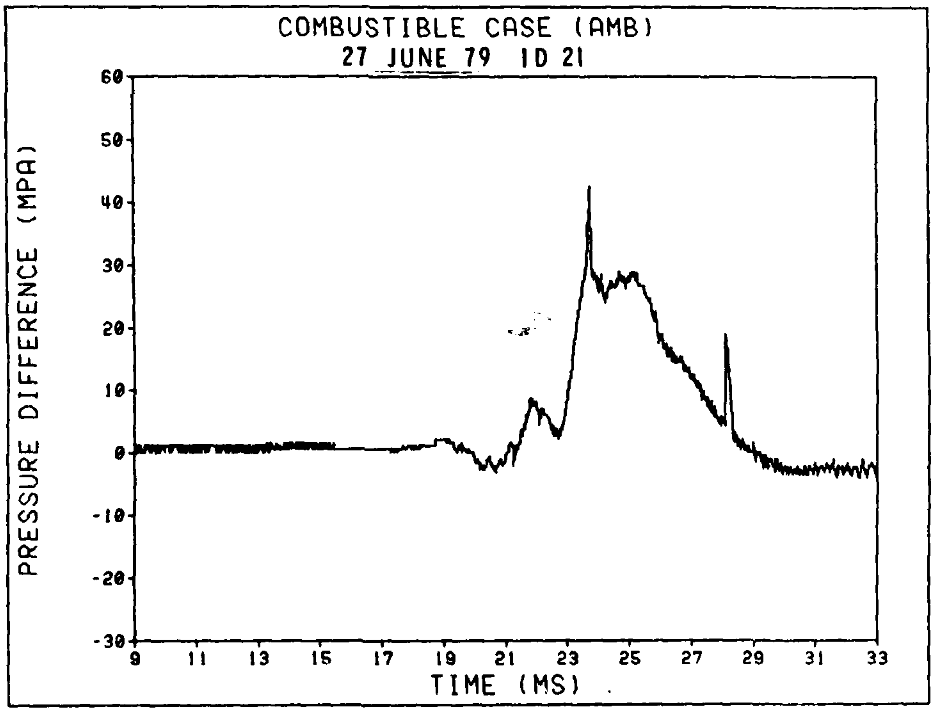
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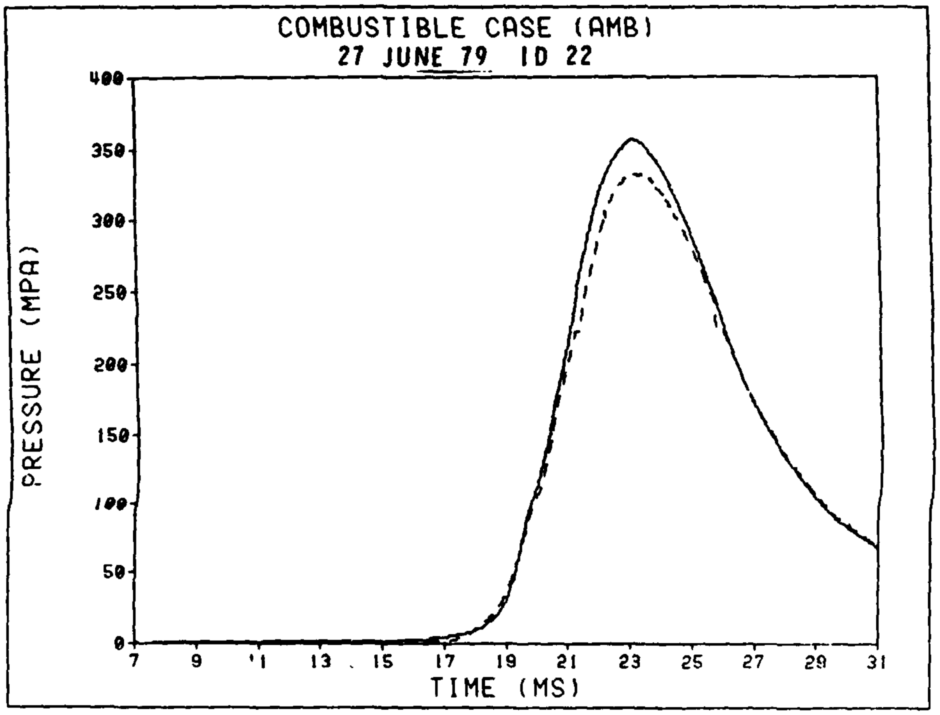
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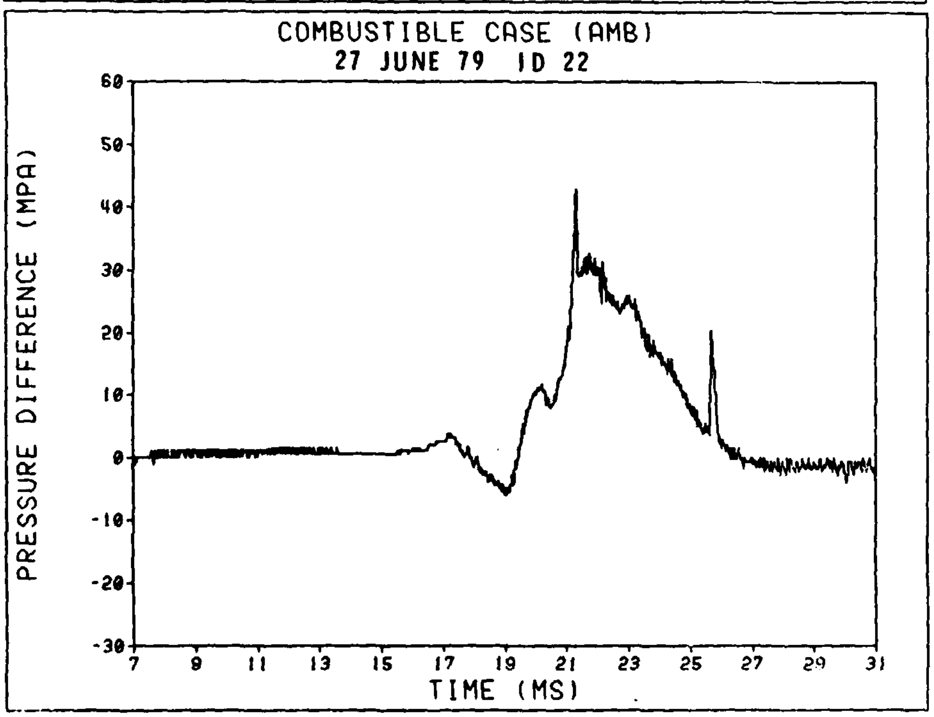
TIME (MS)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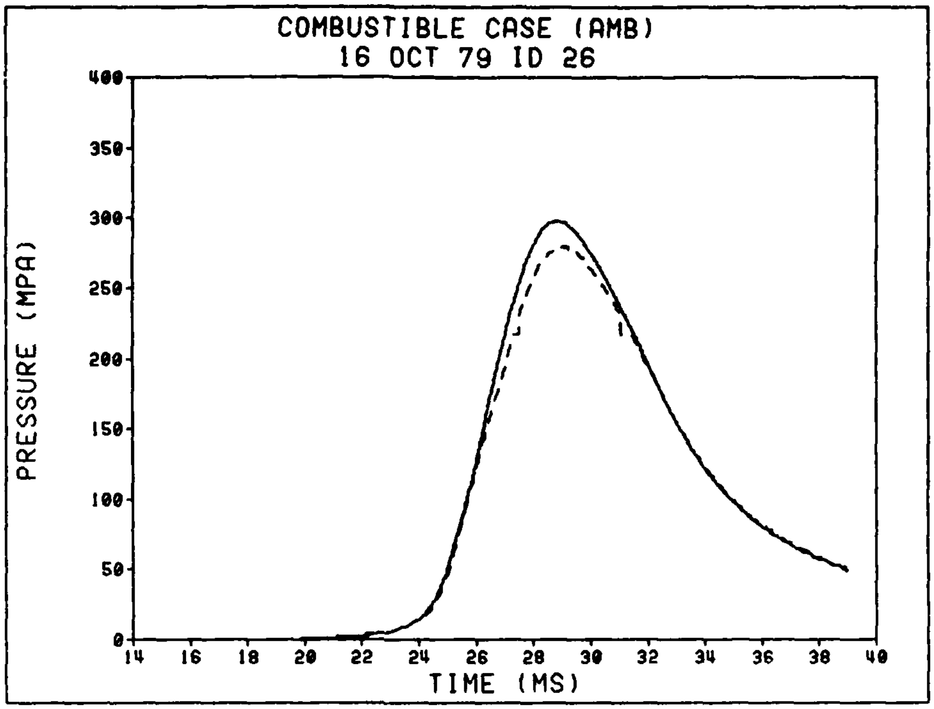
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PRESSURE (MPA)
TIME (MS)
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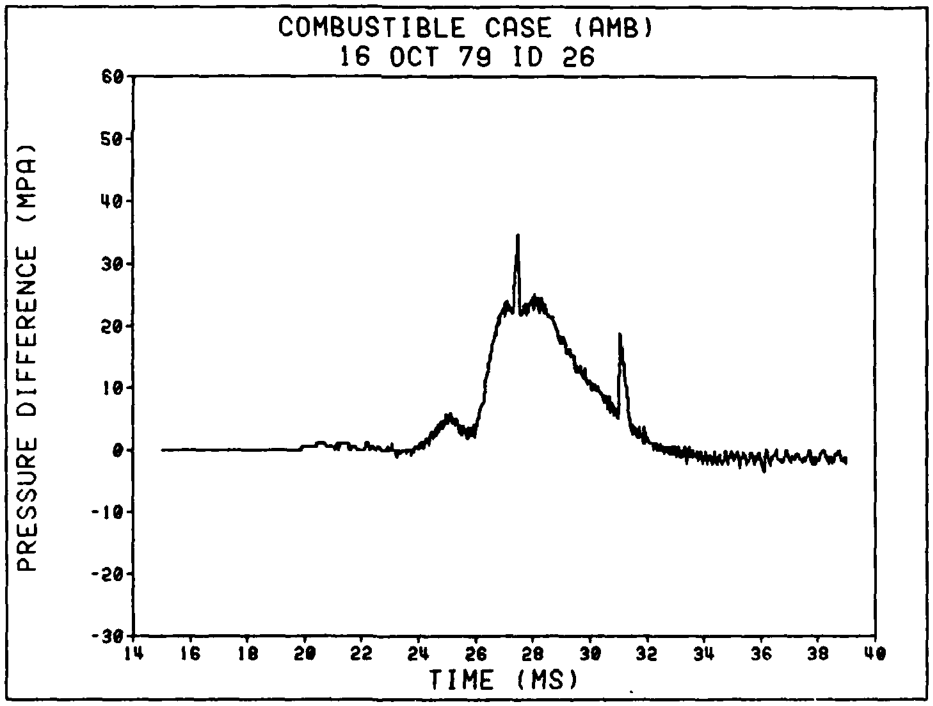
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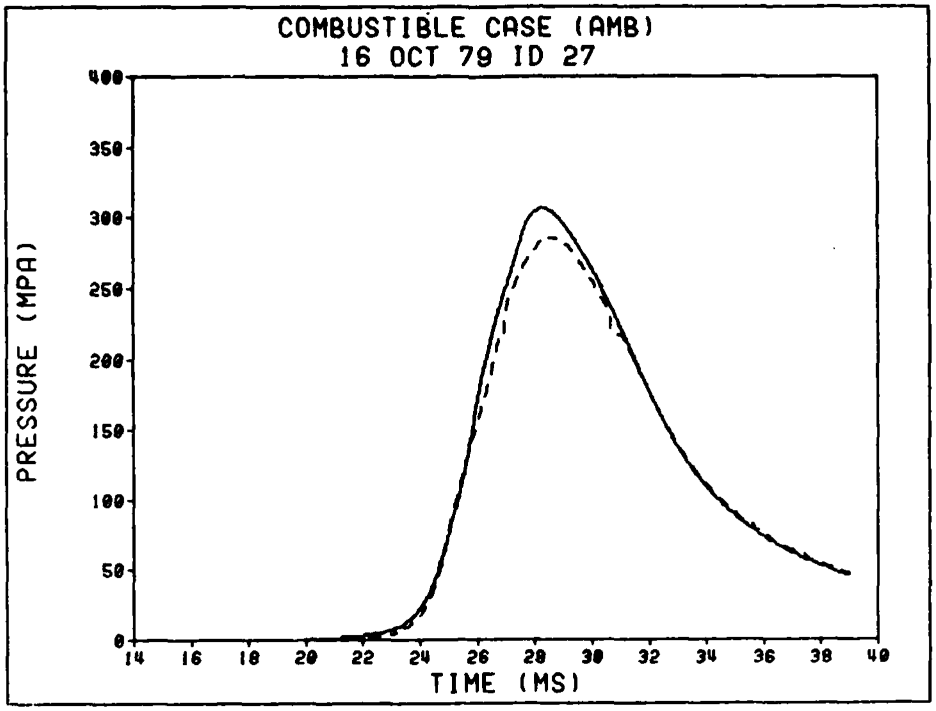
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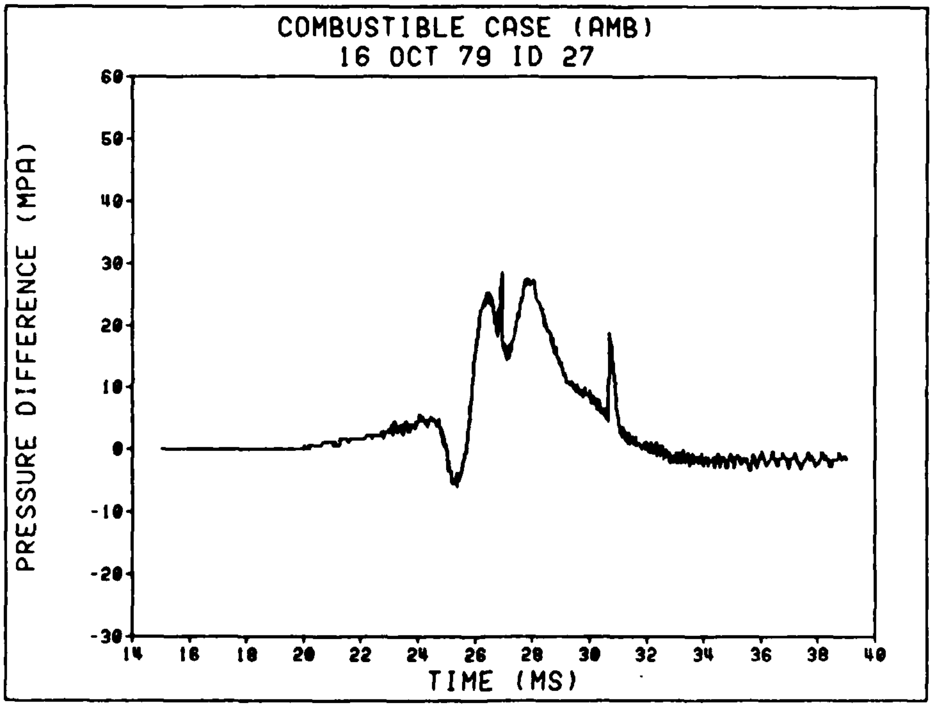
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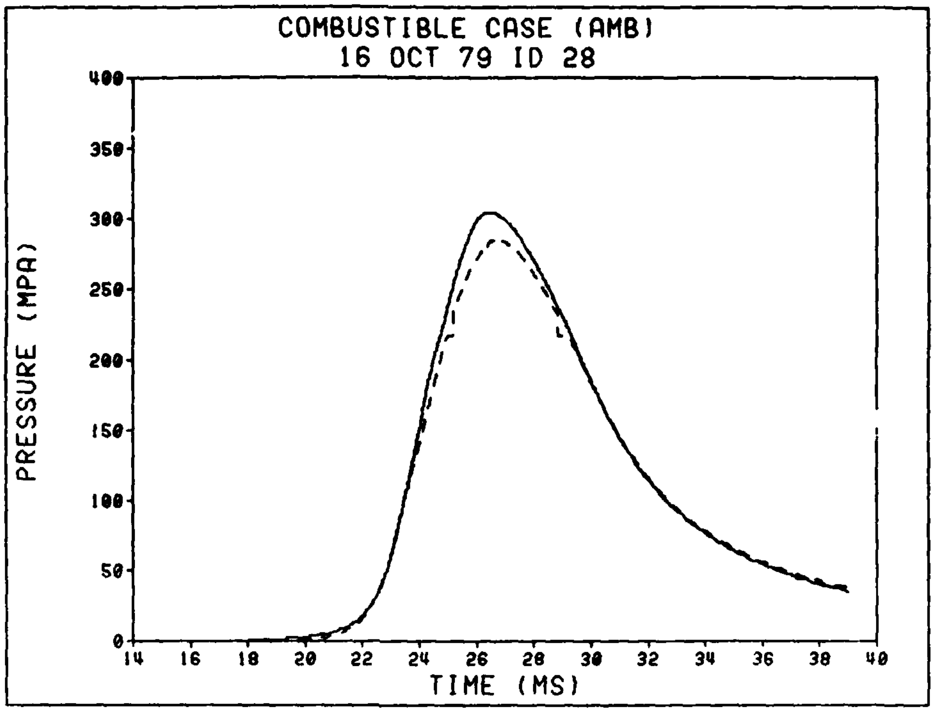
TIME (MS)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100
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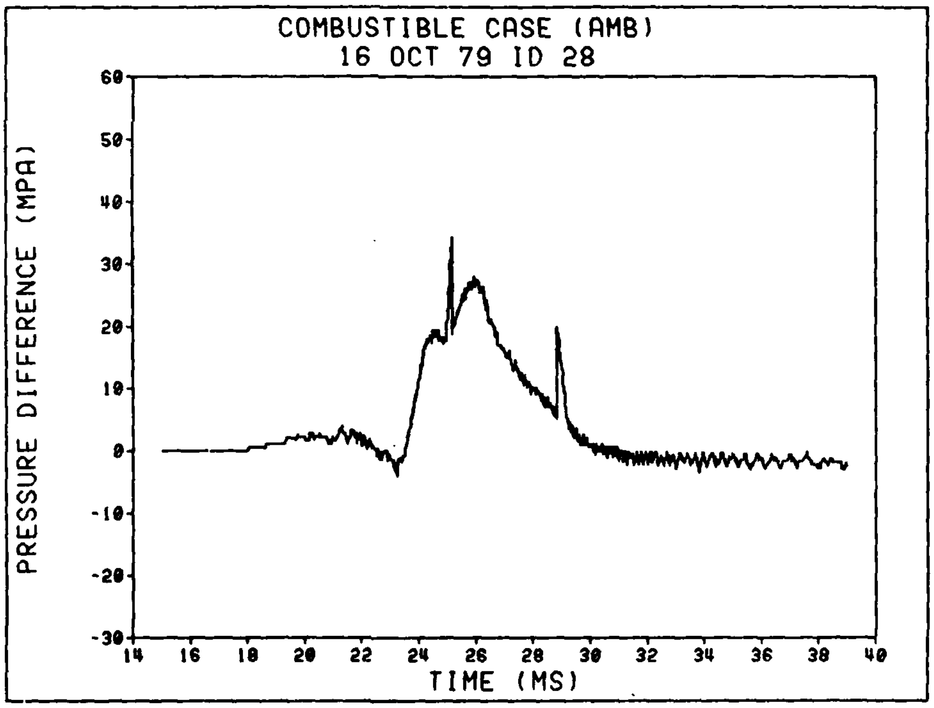
TIME (MS)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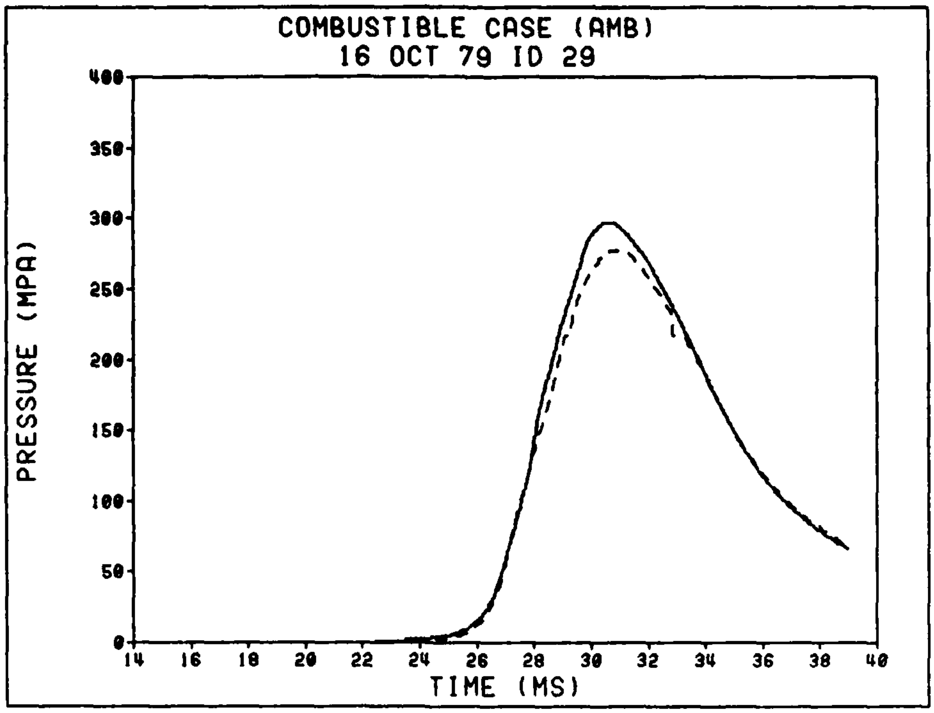
TIME (MS)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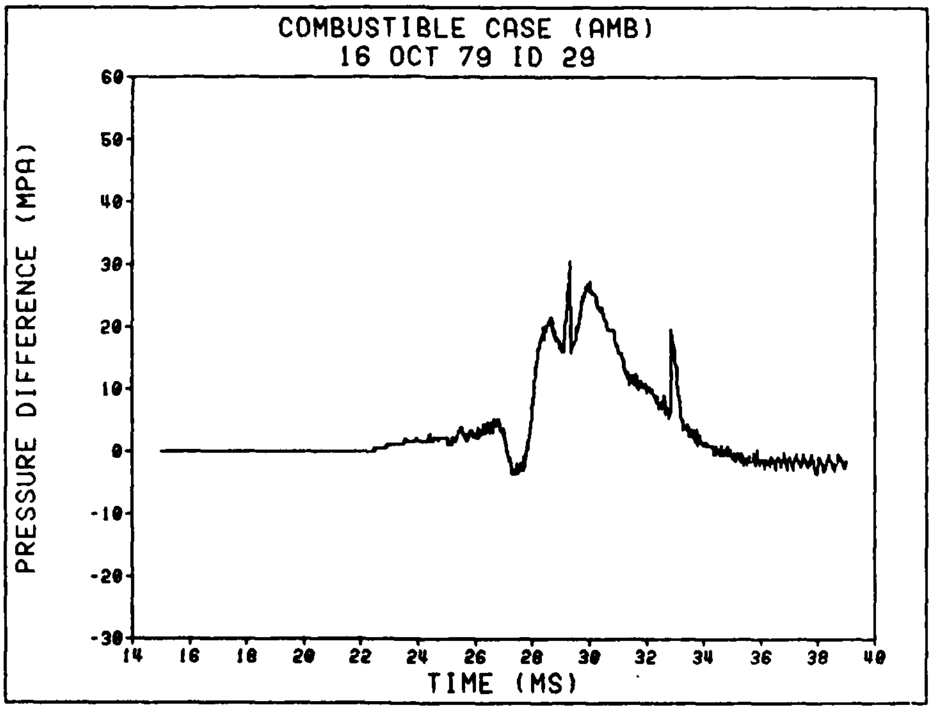
TIME (MS)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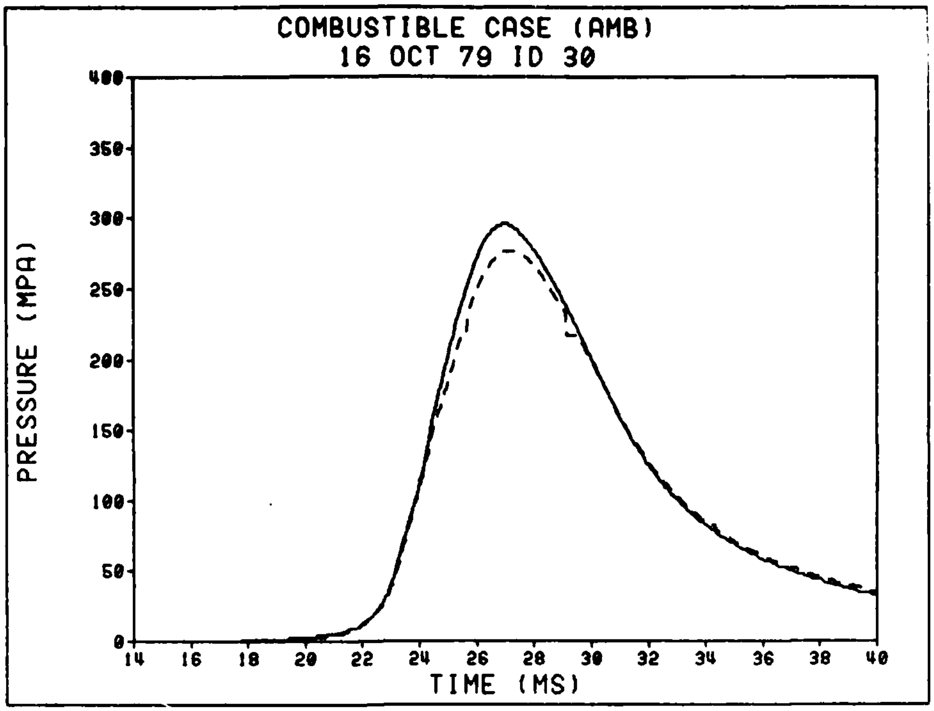
TIME (MS)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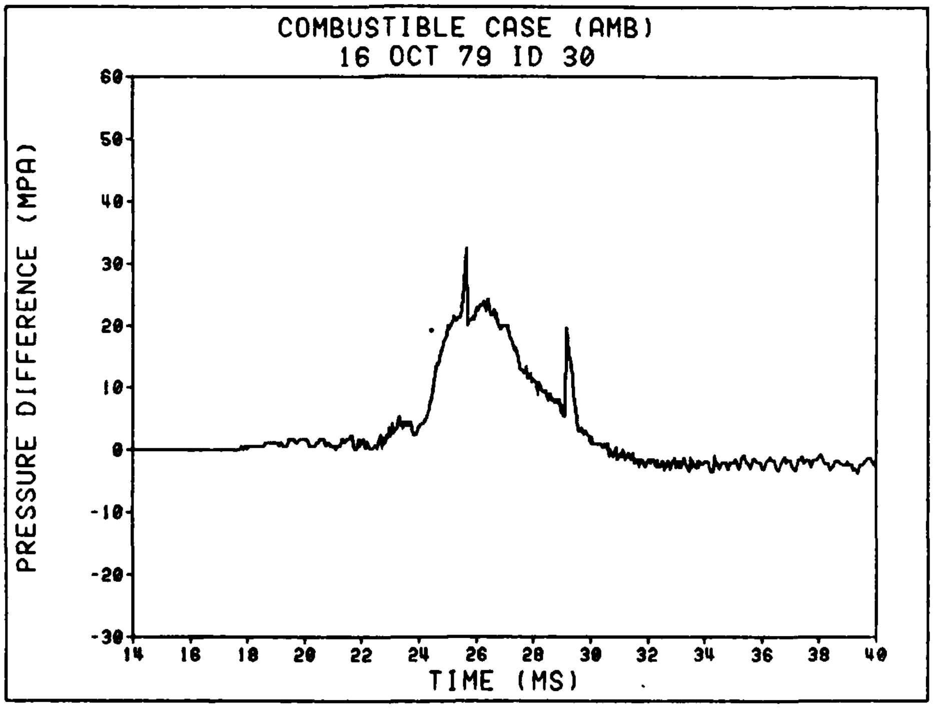
COMBUSTIBLE CASE (AMB)
16 OCT 79 ID 30
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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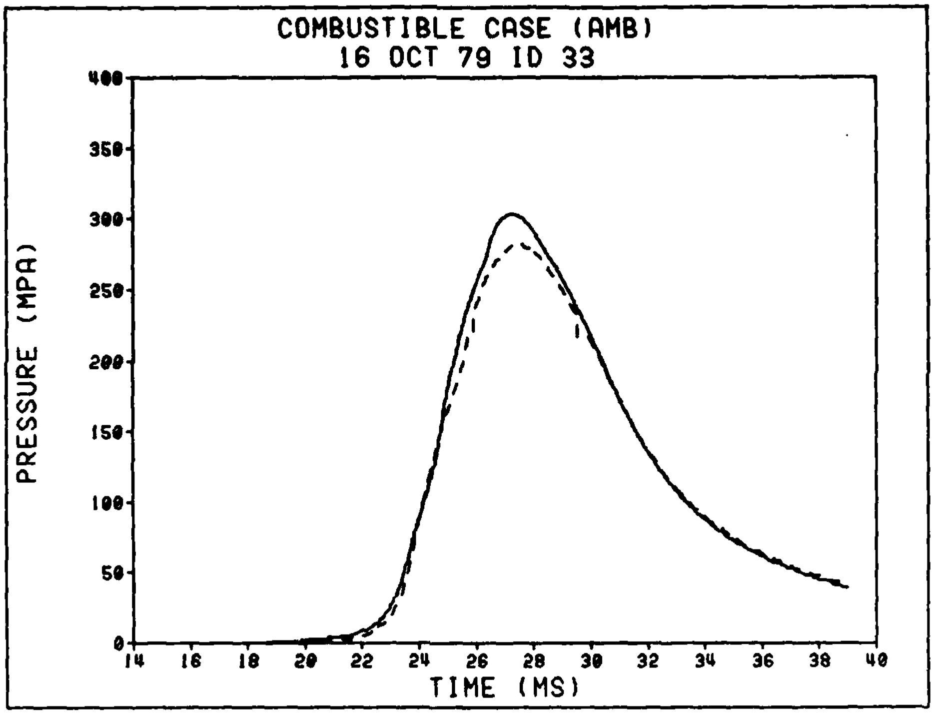
COMBUSTIBLE CASE (AMB)
16 OCT 79 ID 33
PRESSURE (MPA)
TIME (MS)
400
350
300
250
200
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100
50
0
14
16
18
20
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26
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30
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38
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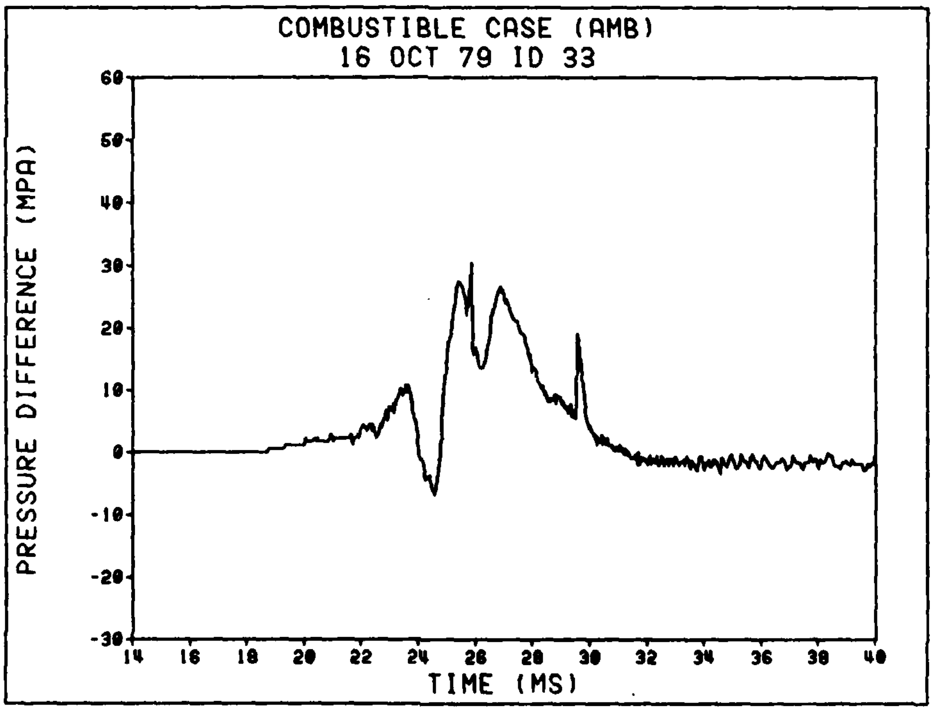
COMBUSTIBLE CASE (AMB)
16 OCT 79 ID 33
PRESSURE DIFFERENCE (MPA)
TIME (MS)
60
50
40
30
20
10
0
-10
-20
-30
14
16
18
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26
28
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34
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38
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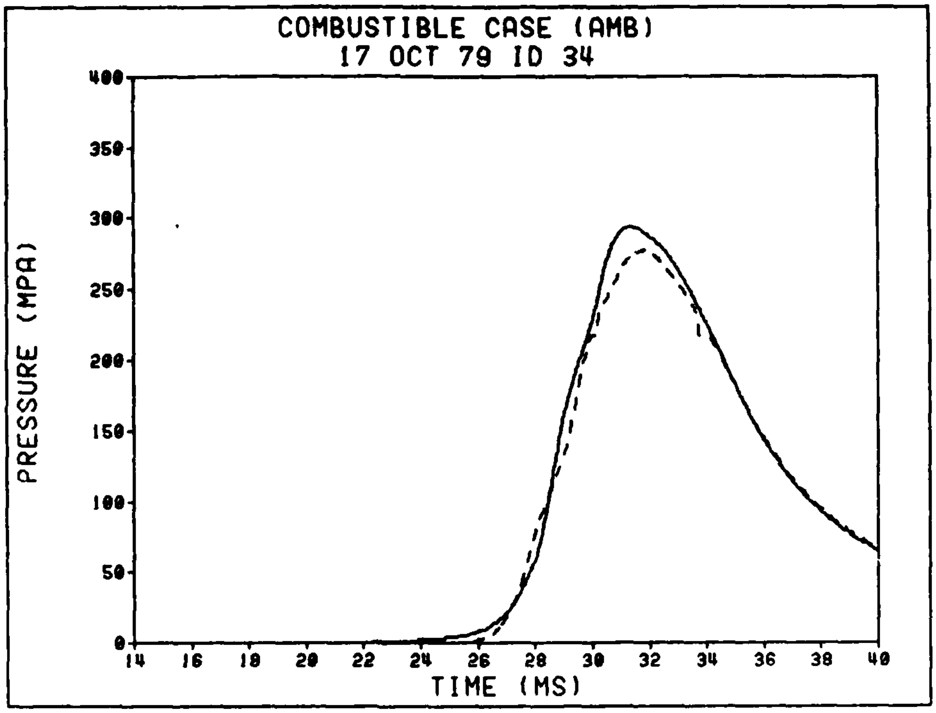
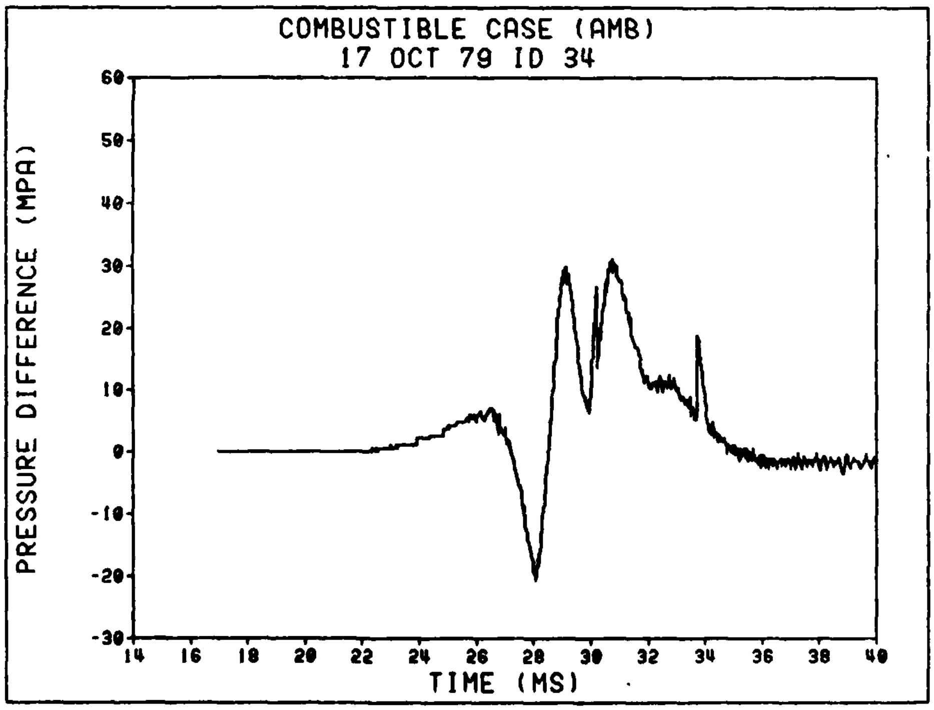
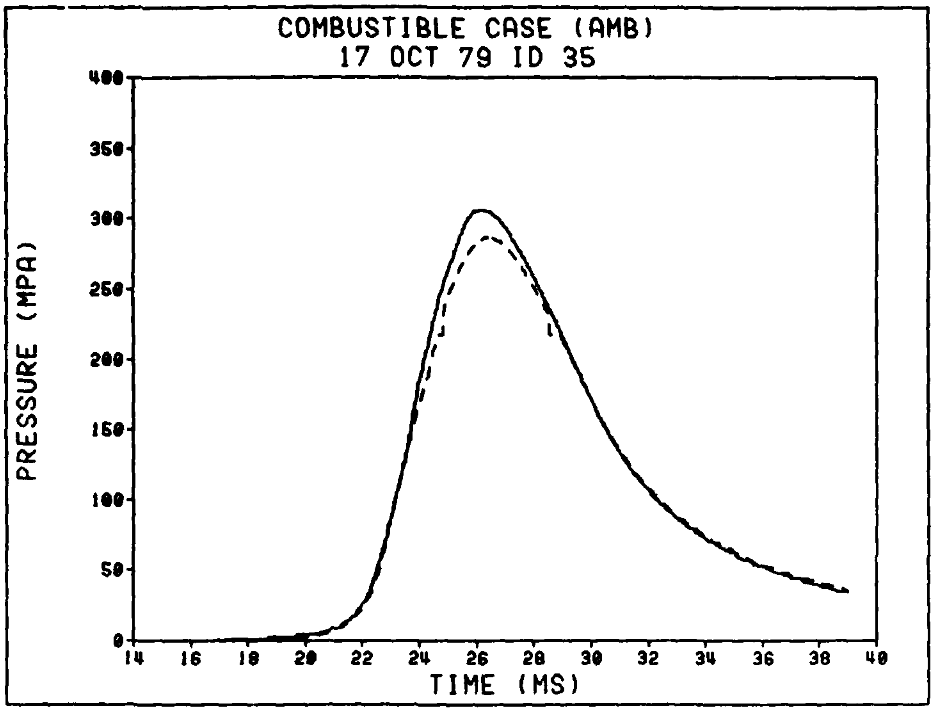

COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 34
PRESSURE (MPA)
400
350
300
250
200
150
100
50
0
14 16 18 20 22 24 26 28 30 32 34 36 38 40
TIME (MS)


COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 34
PRESSURE DIFFERENCE (MPA)
60
50
40
30
20
10
0
-10
-20
-30
14 16 18 20 22 24 26 28 30 32 34 36 38 40
TIME (MS)


COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 35
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
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350
400
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32
34
36
38
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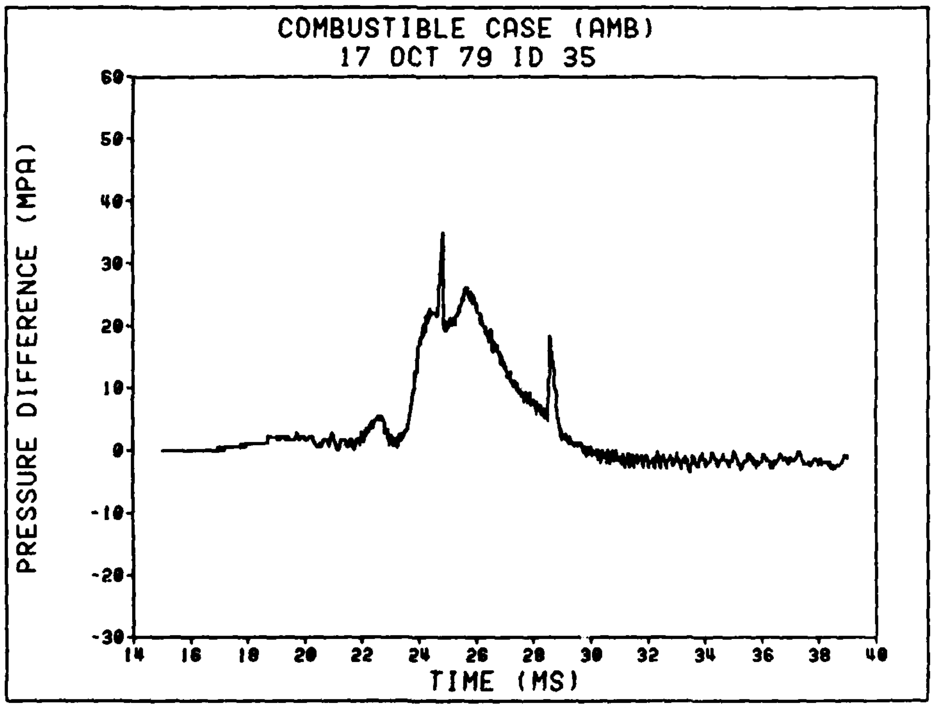
COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 35
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-30
-20
-10
0
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60
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38
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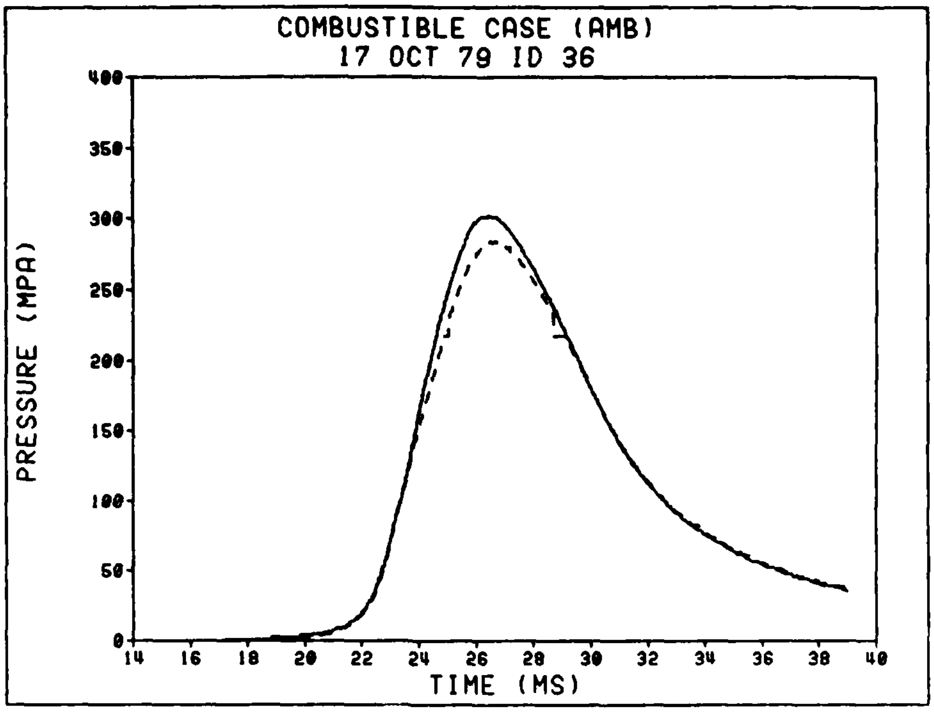
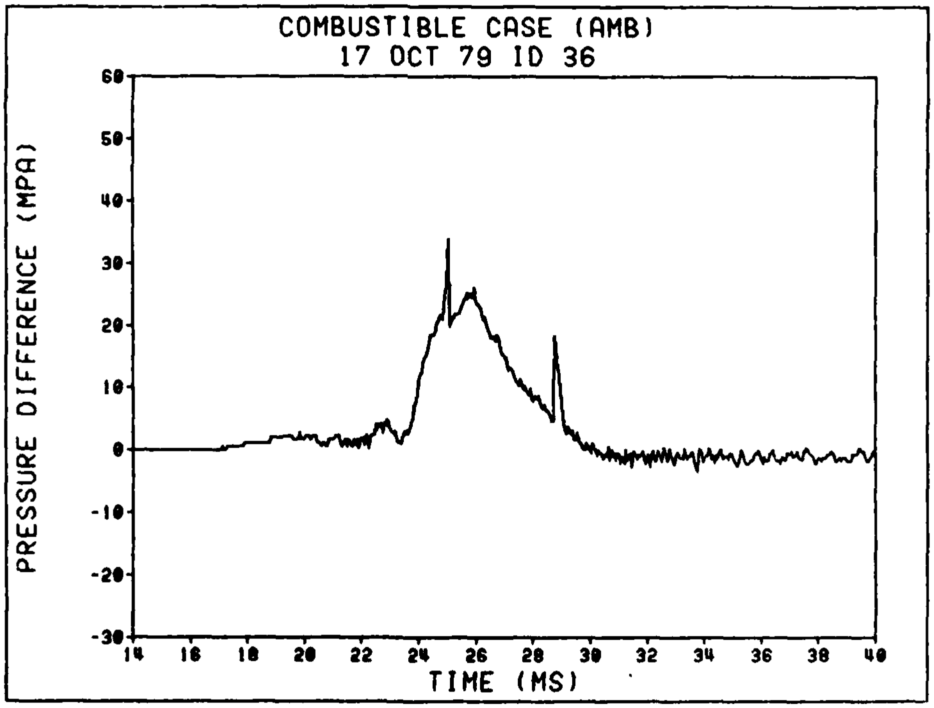
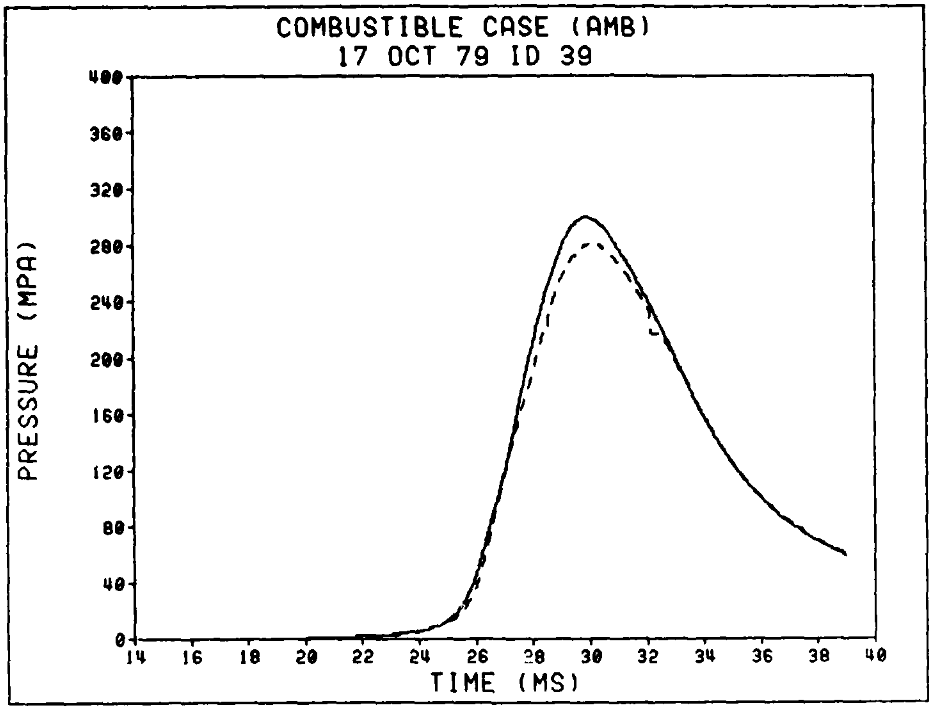
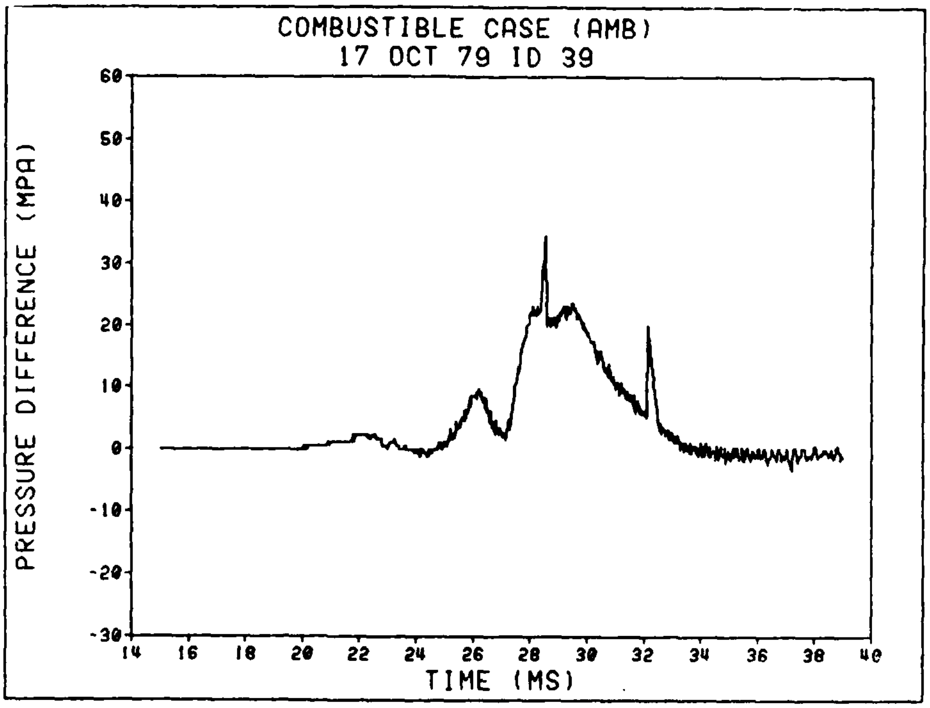


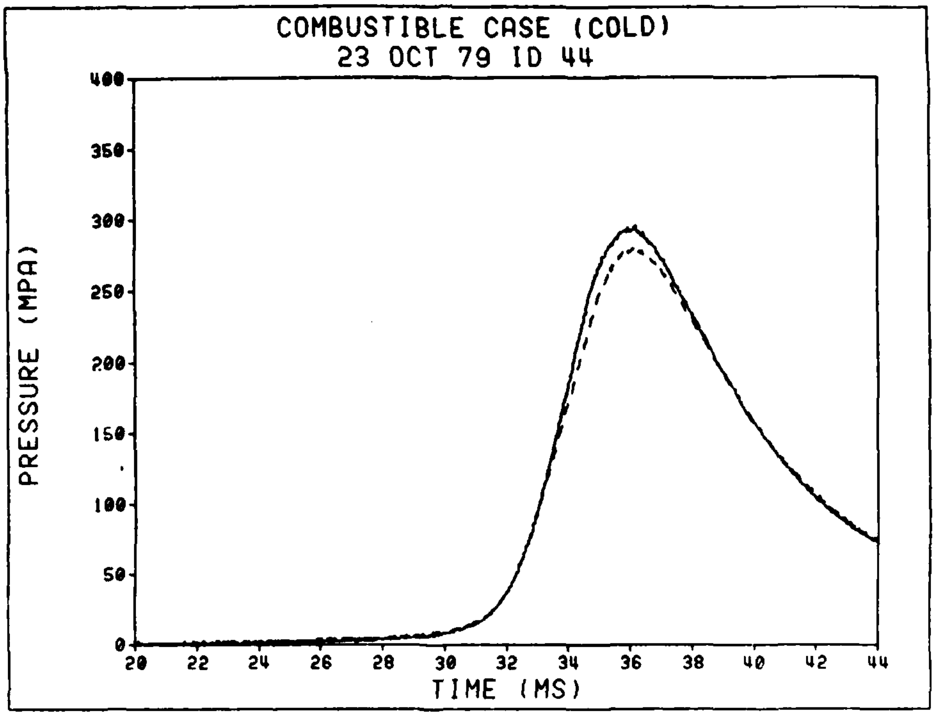
COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 36
PRESSURE (MPA)
TIME (MS)

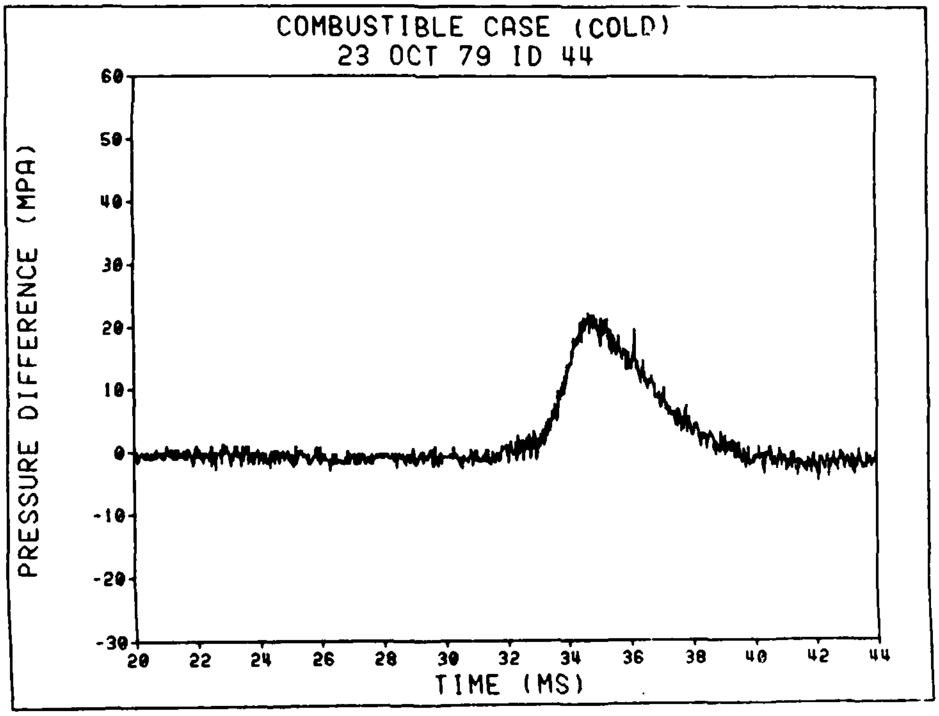


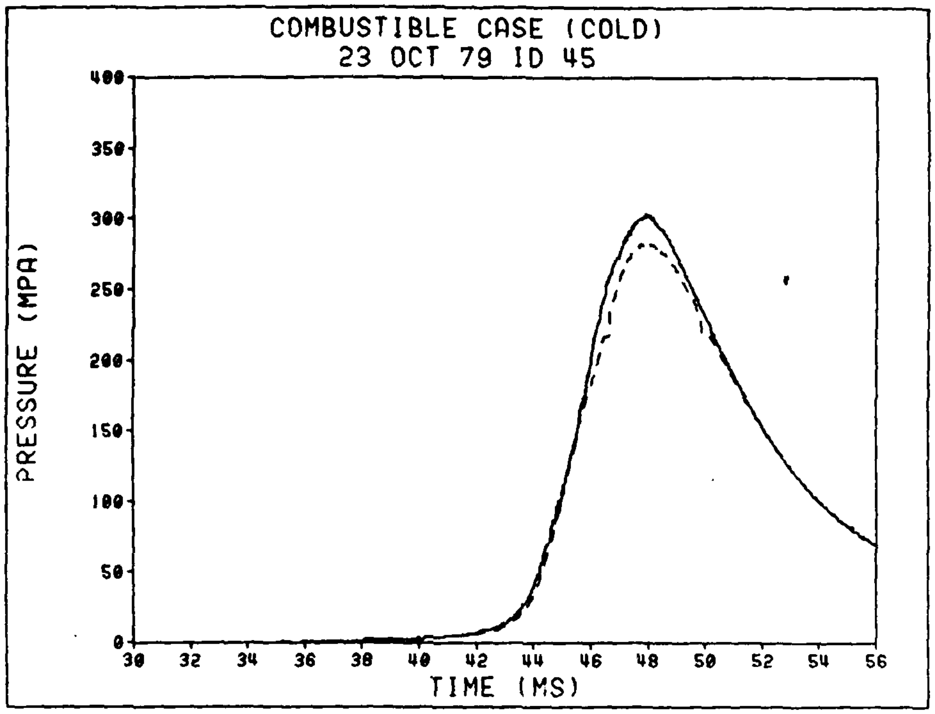
COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 36
PRESSURE DIFFERENCE (MPA)
TIME (MS)

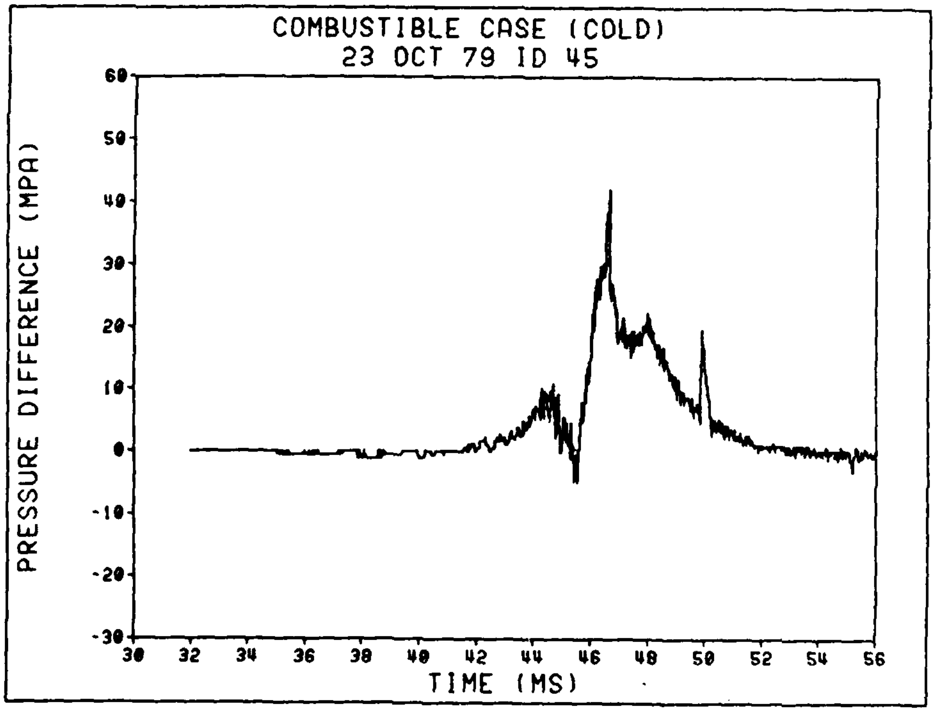

COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 39
PRESSURE (MPA)
TIME (MS)


COMBUSTIBLE CASE (AMB)
17 OCT 79 ID 39
PRESSURE DIFFERENCE (MPA)
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 44
PRESSURE (MPA)
400
350
300
250
200
150
100
50
0
20
22
24
26
28
30
32
34
36
38
40
42
44
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 44
PRESSURE DIFFERENCE (MPA)
60
50
40
30
20
10
0
-10
-20
-30
20
22
24
26
28
30
32
34
36
38
40
42
44
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 45
PRESSURE (MPA)
400
350
300
250
200
150
100
50
0
30 32 34 36 38 40 42 44 46 48 50 52 54 56
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 45
PRESSURE DIFFERENCE (MPA)
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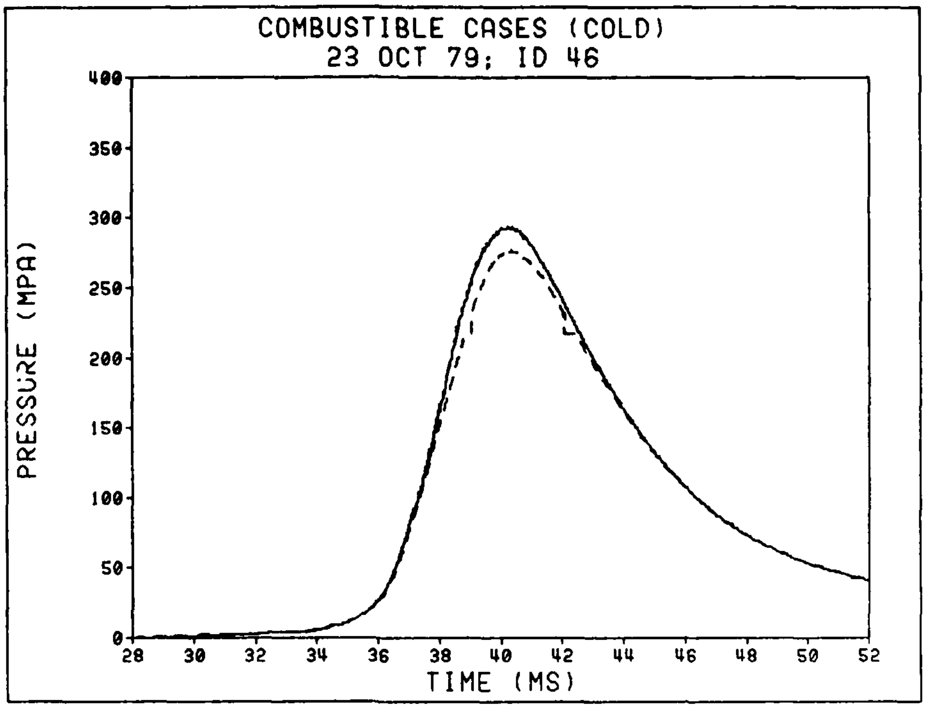
40
30
20
10
0
-10
-20
-30
30 32 34 36 38 40 42 44 46 48 50 52 54 56
TIME (MS)


COMBUSTIBLE CASES (COLD)
23 OCT 79; ID 46
PRESSURE (MPA)
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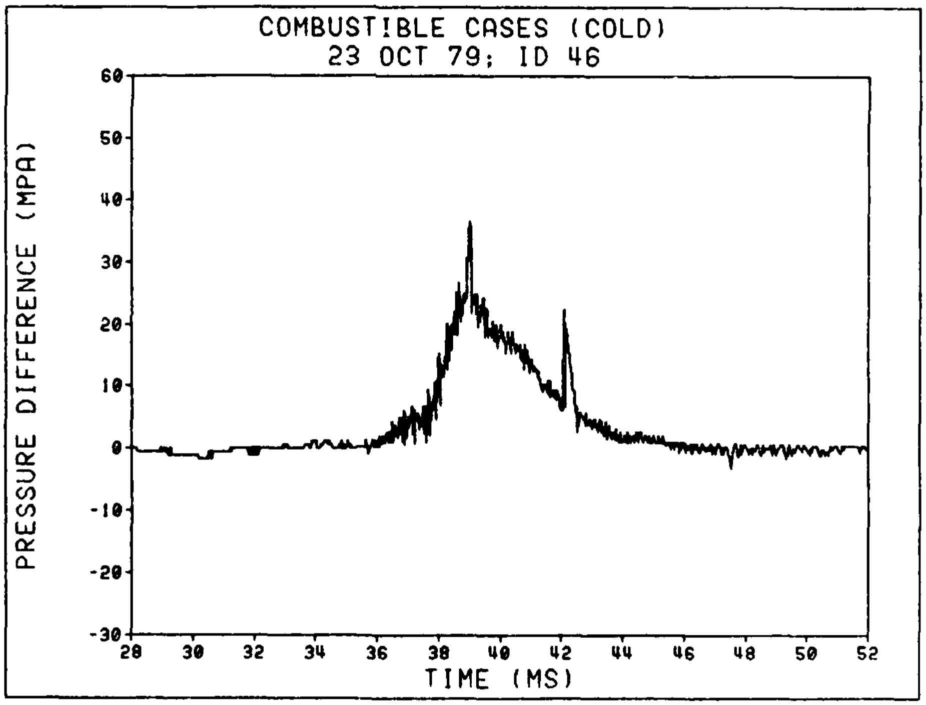
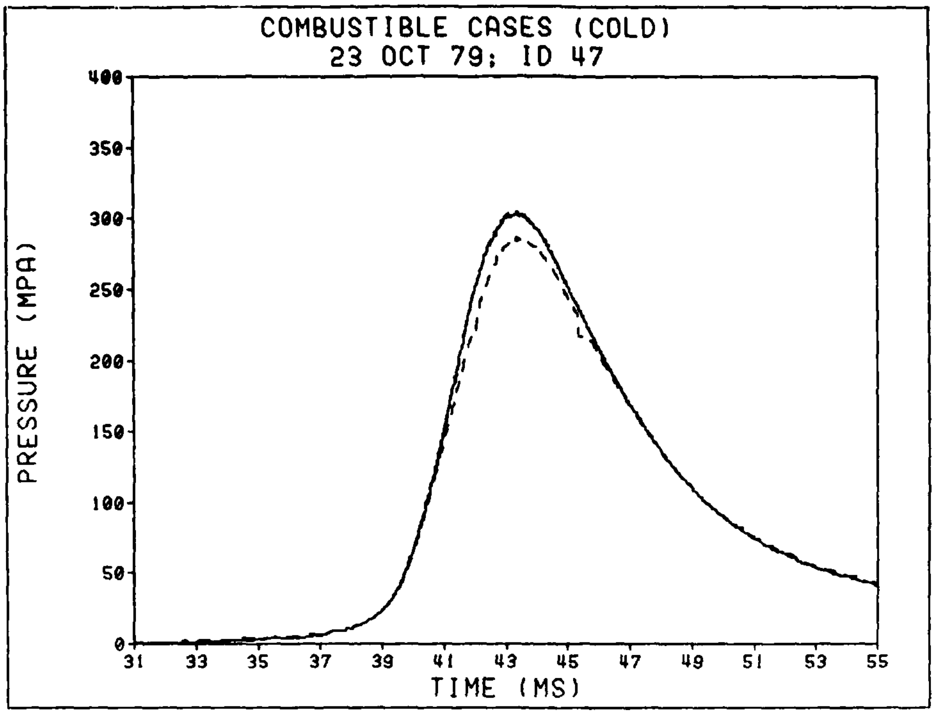
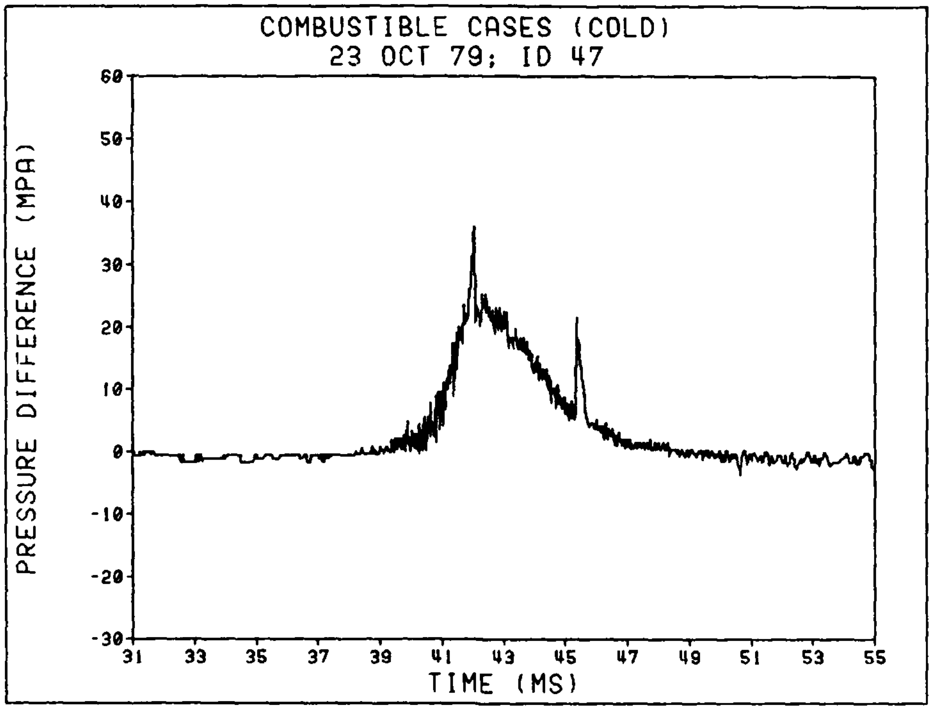
350
300
250
200
150
100
50
0
28
30
32
34
36
38
40
42
44
46
48
50
52
TIME (MS)


COMBUSTIBLE CASES (COLD)
23 OCT 79; ID 46
PRESSURE DIFFERENCE (MPA)
60
50
40
30
20
10
0
-10
-20
-30
28
30
32
34
36
38
40
42
44
46
48
50
52
TIME (MS)


COMBUSTIBLE CASES (COLD)
23 OCT 79; ID 47
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
31
33
35
37
39
41
43
45
47
49
51
53
55


COMBUSTIBLE CASES (COLD)
23 OCT 79; ID 47
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-30
-20
-10
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60
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33
35
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41
43
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49
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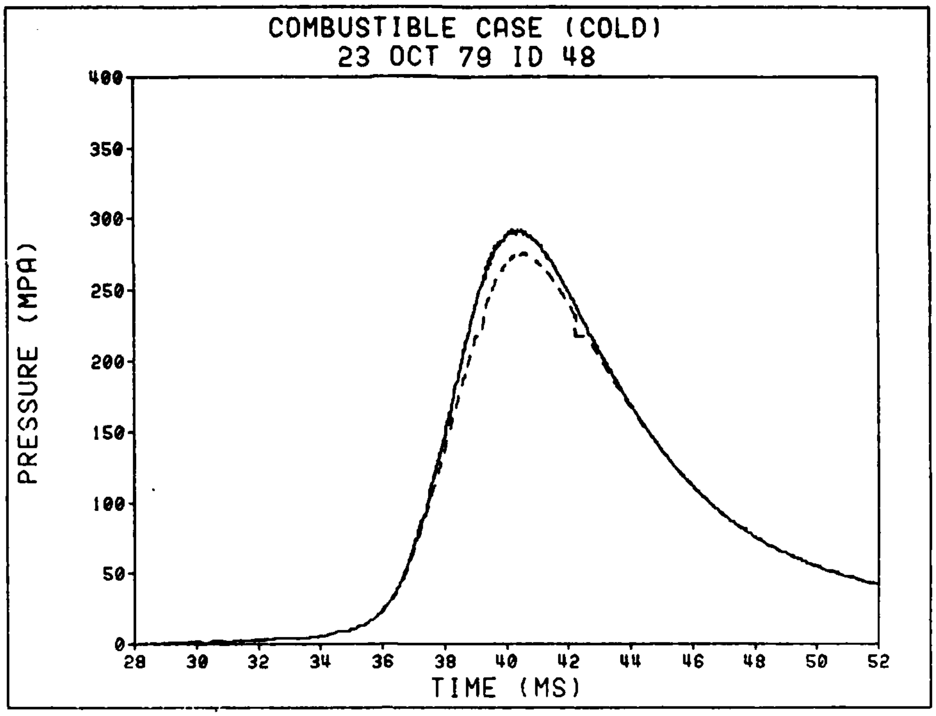
53
55



COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 48
PRESSURE (MPA)
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350
300
250
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150
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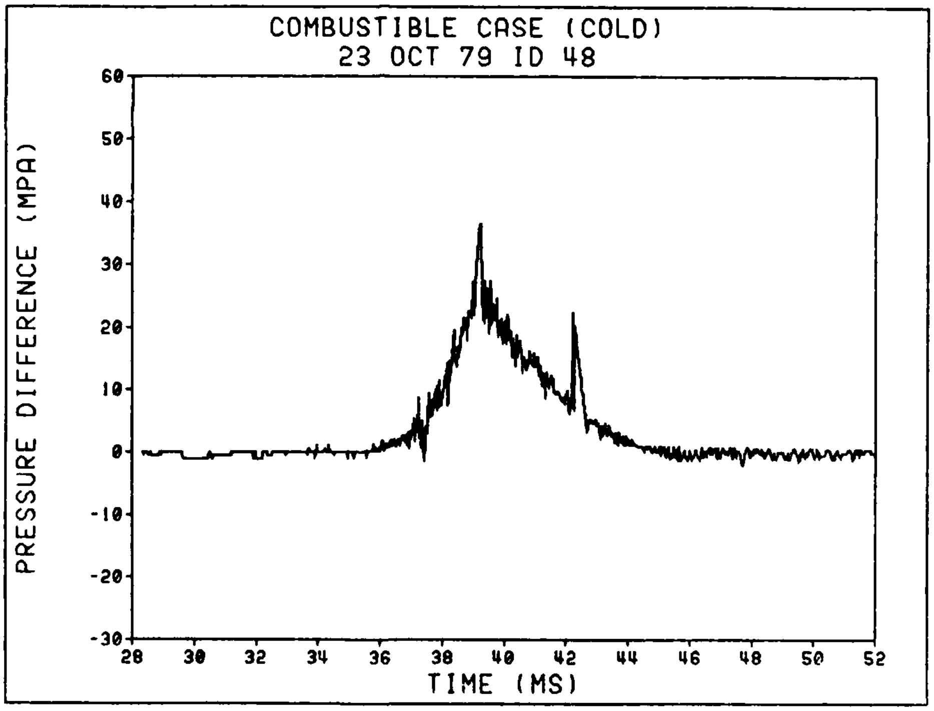
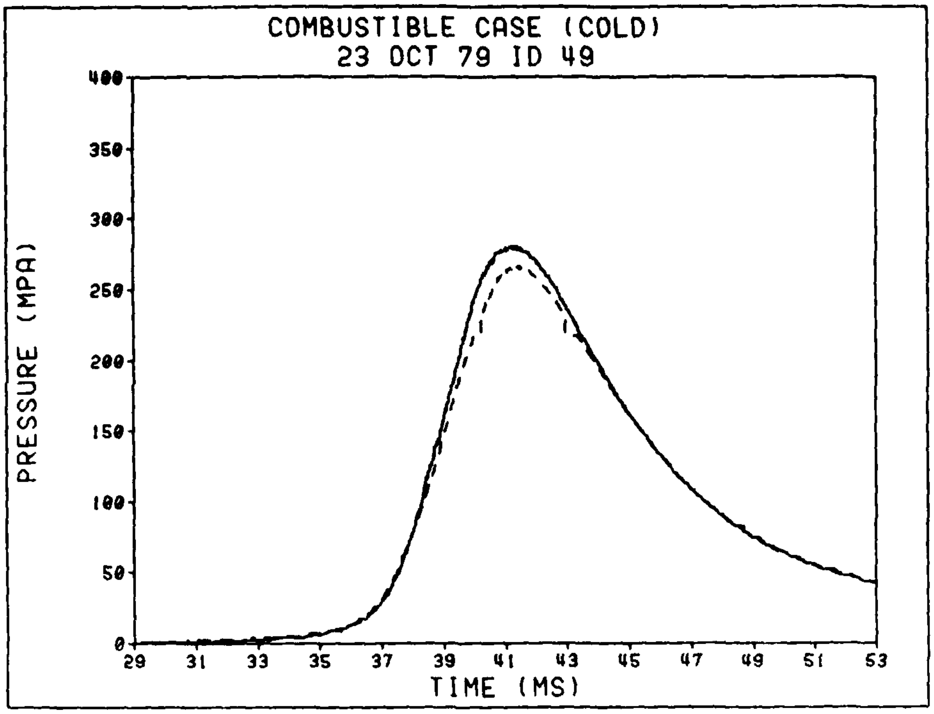
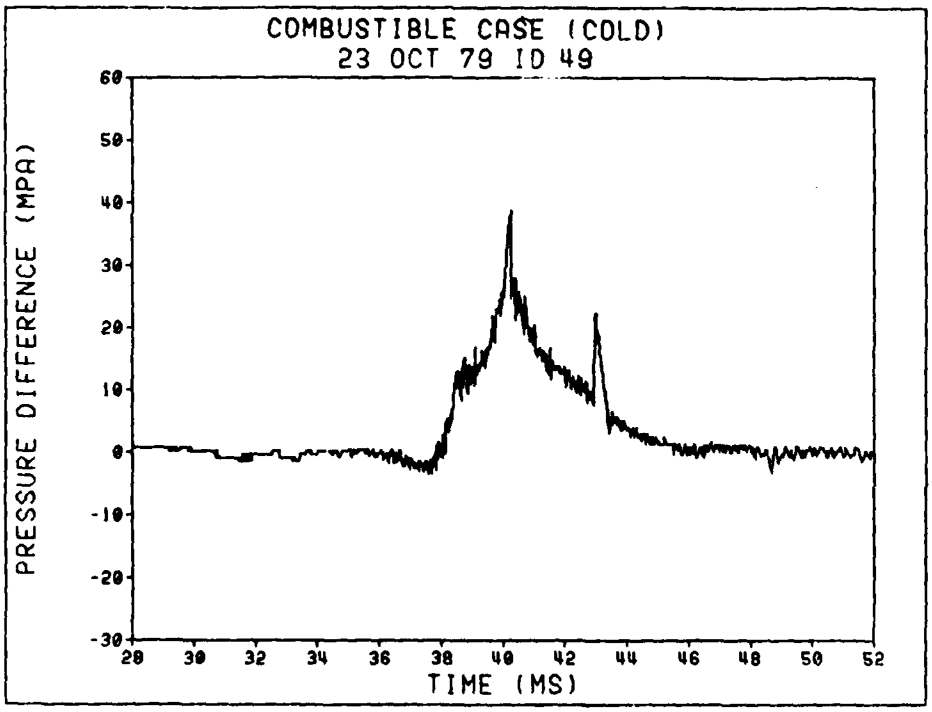
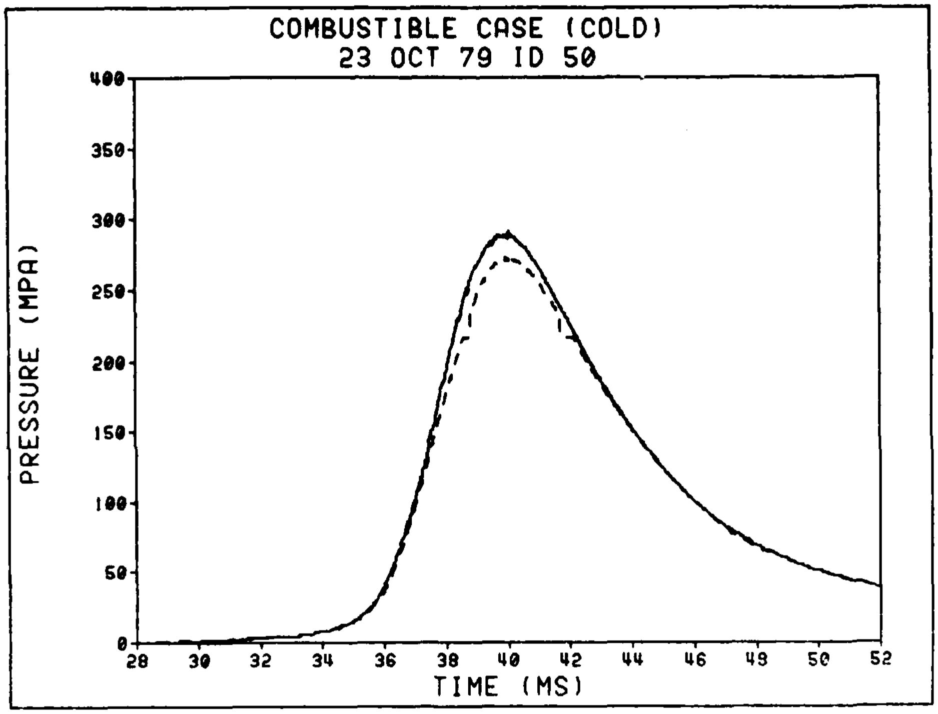
0
28
30
32
34
36
38
40
42
44
46
48
50
52
TIME (MS)



COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 48
PRESSURE DIFFERENCE (MPA)
60
50
40
30
20
10
0
-10
-20
-30
28
30
32
34
36
38
40
42
44
46
48
50
52
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 49
PRESSURE (MPA)
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 49
PRESSURE DIFFERENCE (MPA)
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 50
PRESSURE (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
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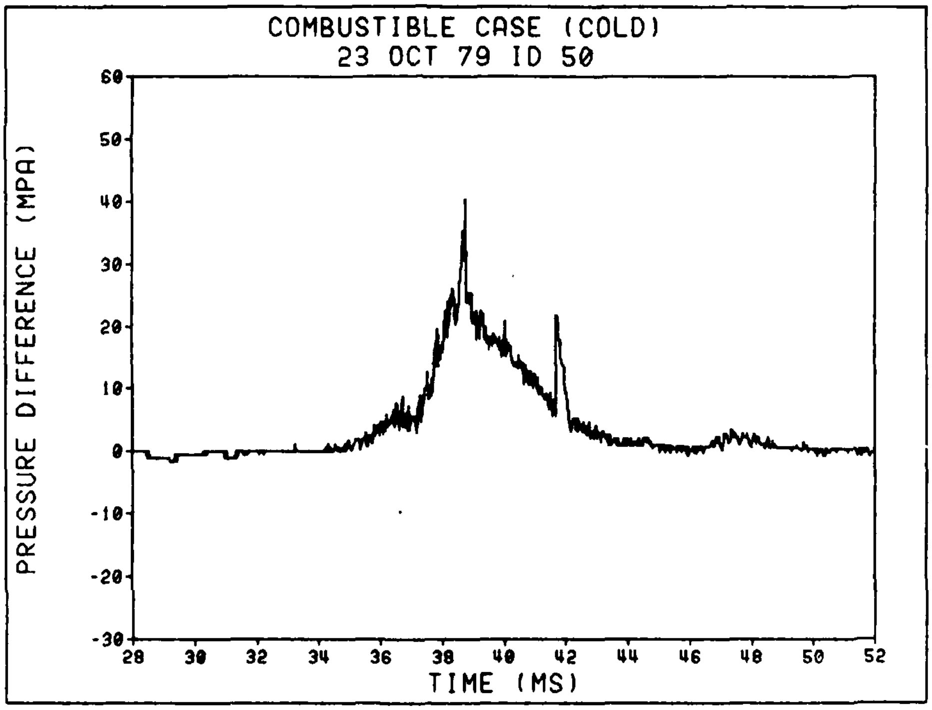
30
32
34
36
38
40
42
44
46
48
50
52


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 50
PRESSURE DIFFERENCE (MPA)
TIME (MS)
60
50
40
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10
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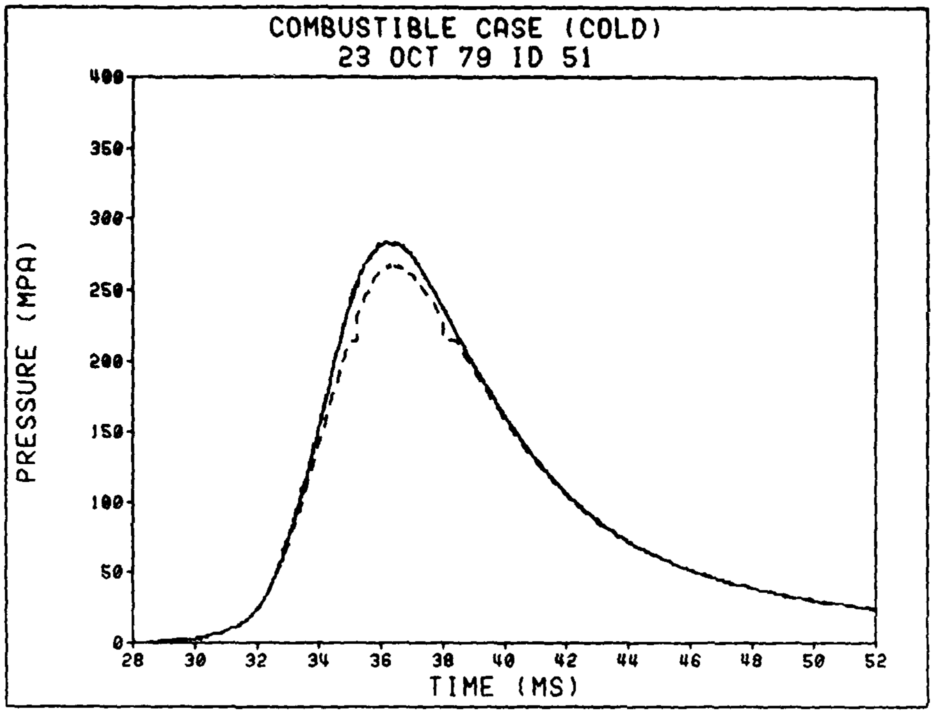
44
46
48
50
52


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 51
PRESSURE (MPA)
TIME (MS)
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300
350
400
28
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32
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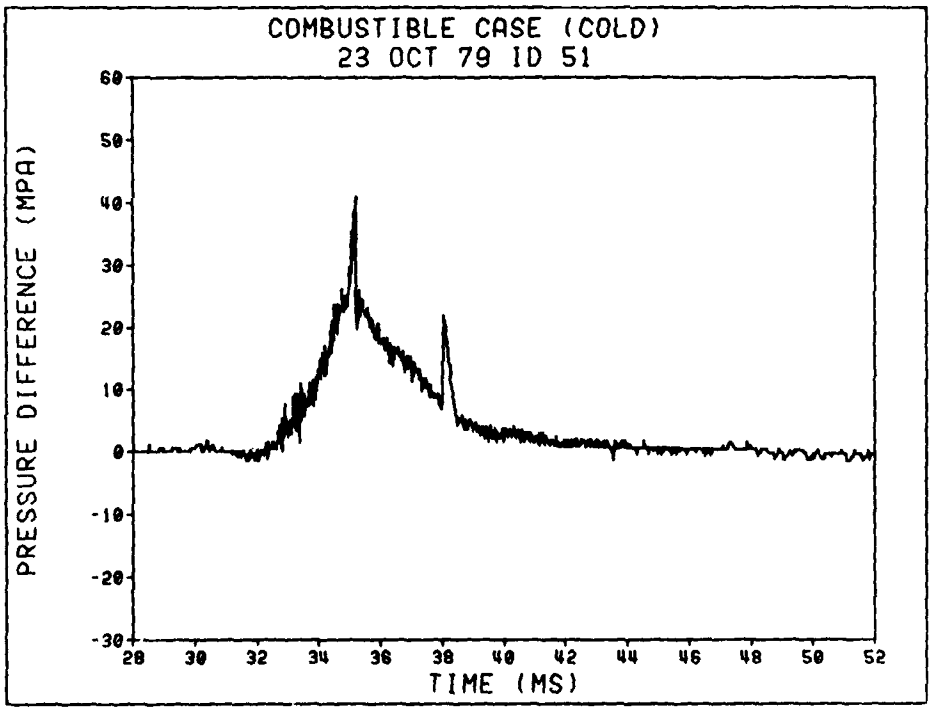
38
40
42
44
46
48
50
52


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 51
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-30
-20
-10
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50
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38
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42
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46
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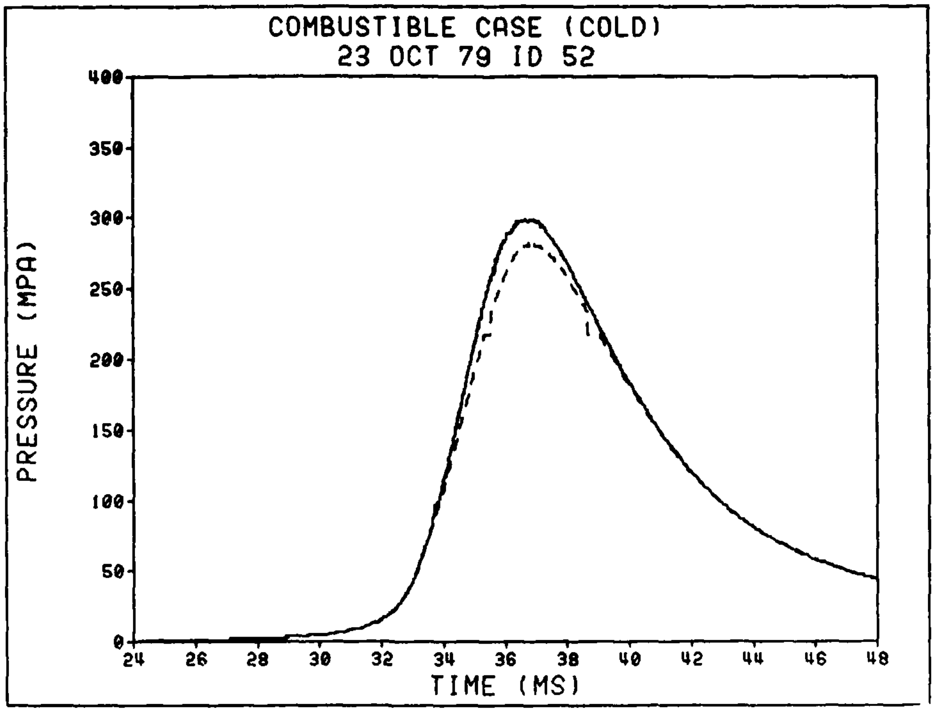
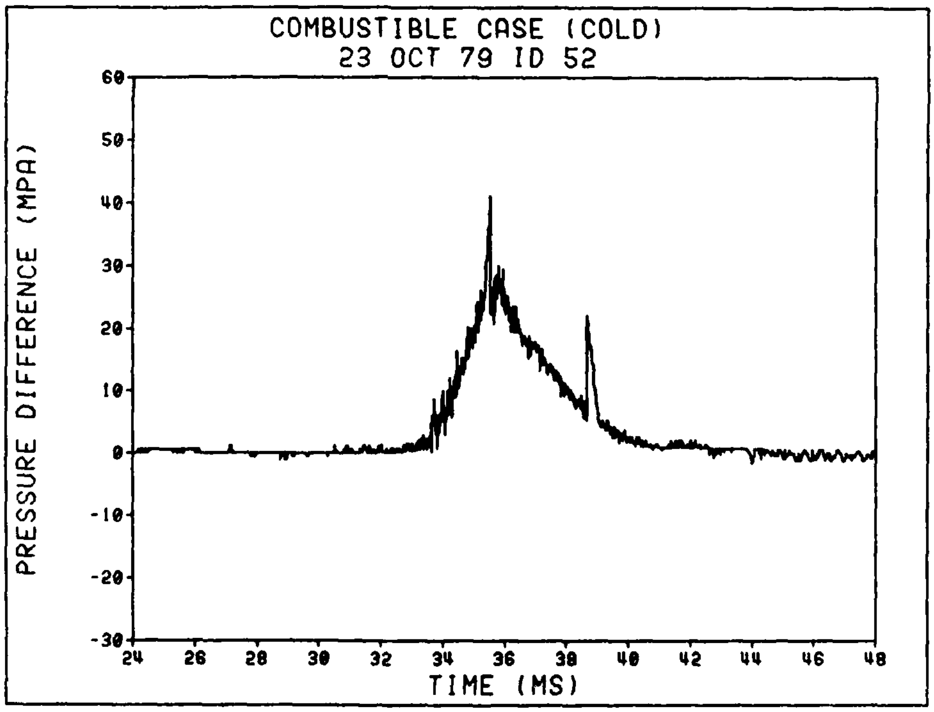

COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 52
PRESSURE (MPA)
400
350
300
250
200
150
100
50
0
24 26 28 30 32 34 36 38 40 42 44 46 48
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 52
PRESSURE DIFFERENCE (MPA)
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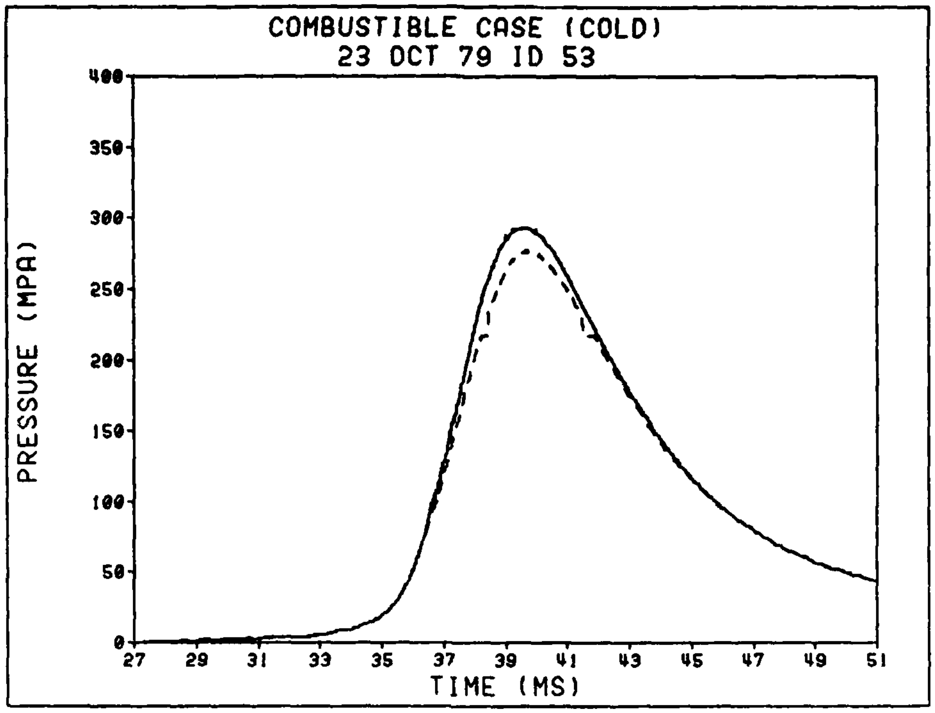
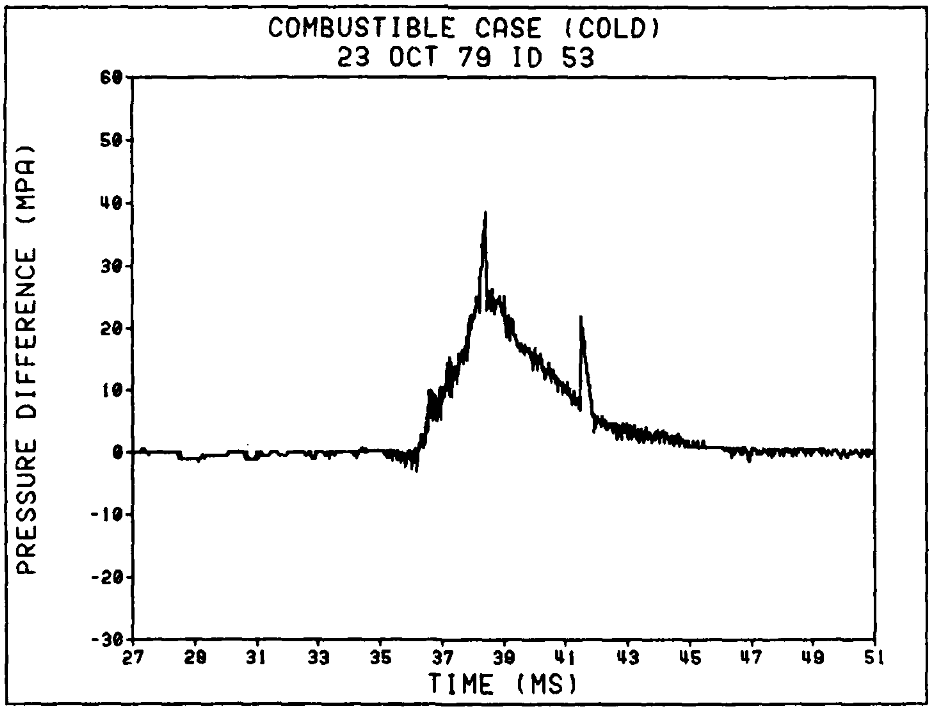
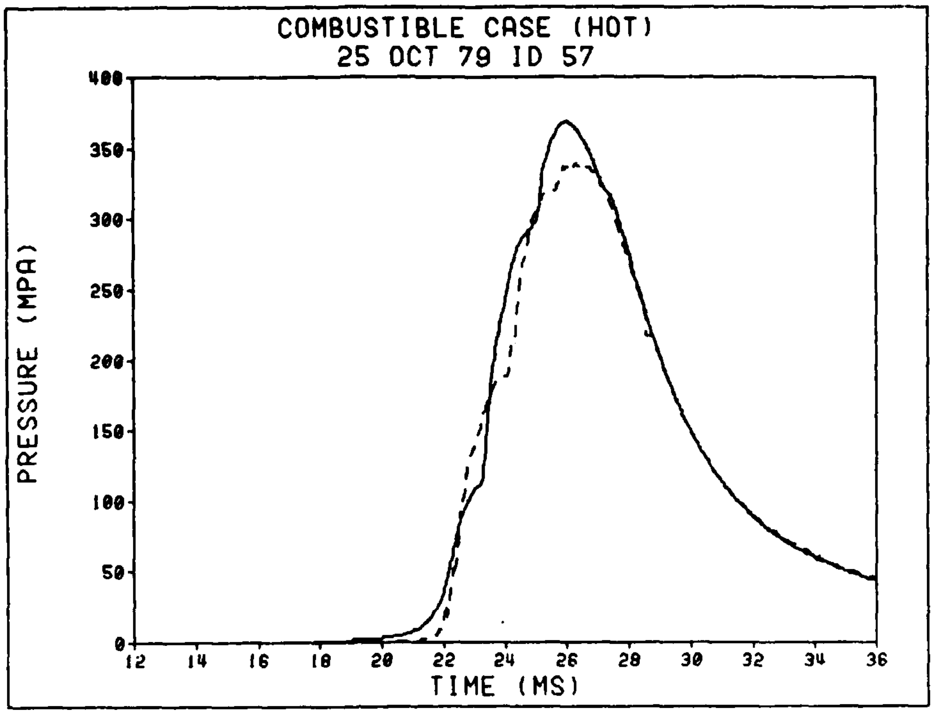
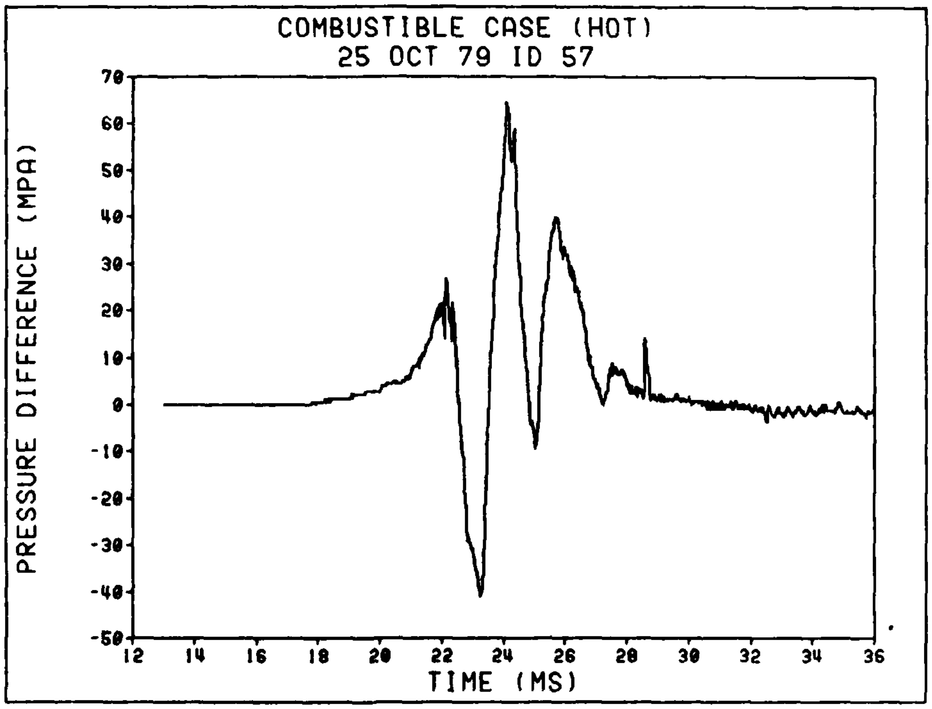
40
30
20
10
0
-10
-20
-30
24 26 28 30 32 34 36 38 40 42 44 46 48
TIME (MS)


COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 53
PRESSURE (MPA)
TIME (MS)

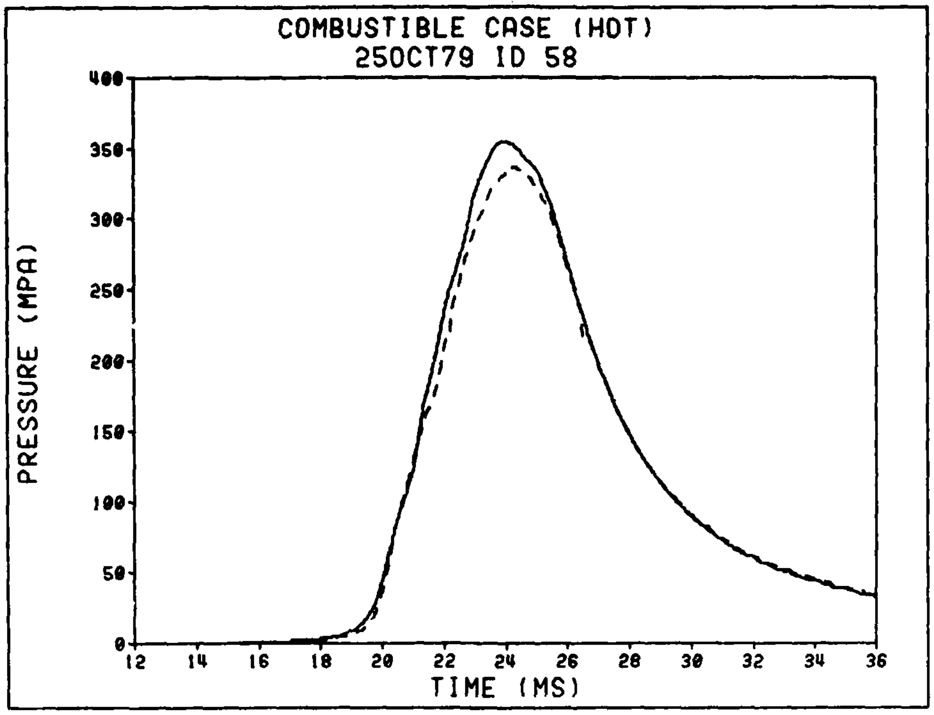

COMBUSTIBLE CASE (COLD)
23 OCT 79 ID 53
PRESSURE DIFFERENCE (MPA)
TIME (MS)

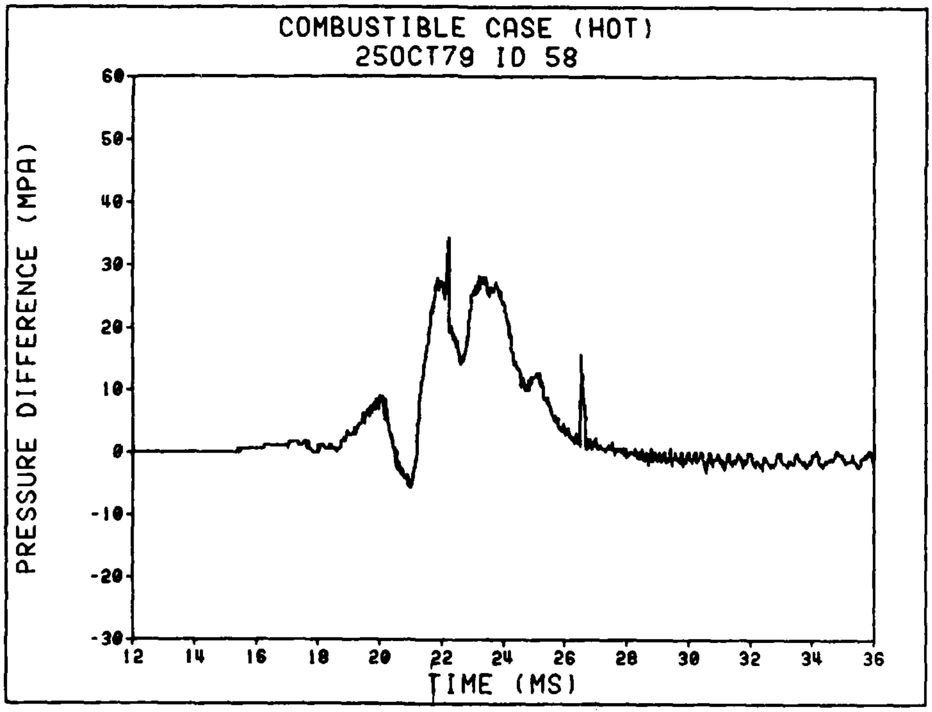


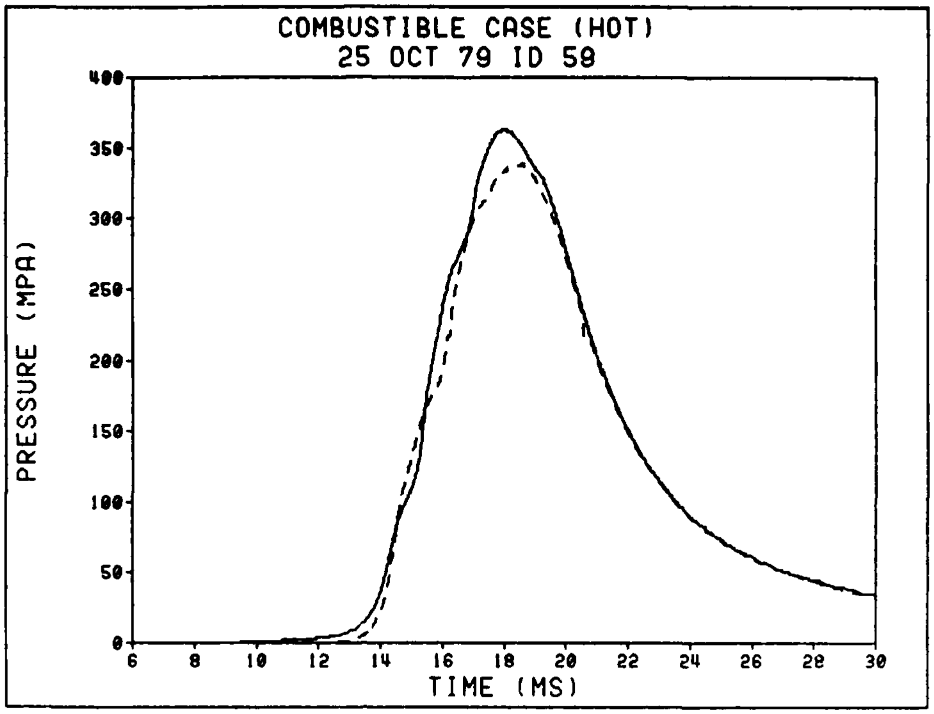
COMBUSTIBLE CASE (HOT)
25 OCT 79 ID 57
PRESSURE (MPA)
TIME (MS)

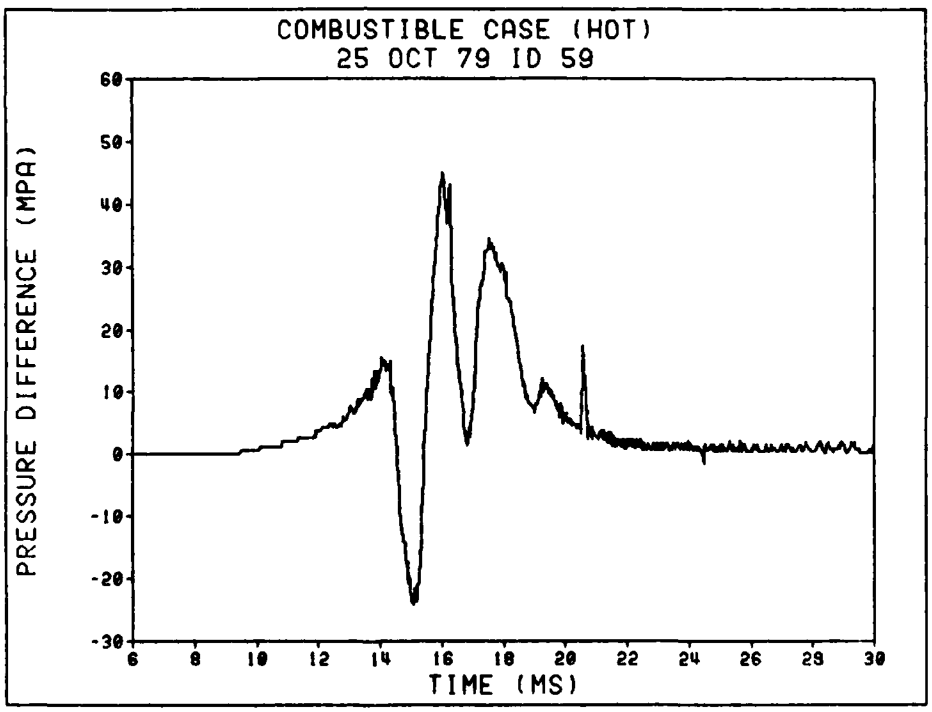


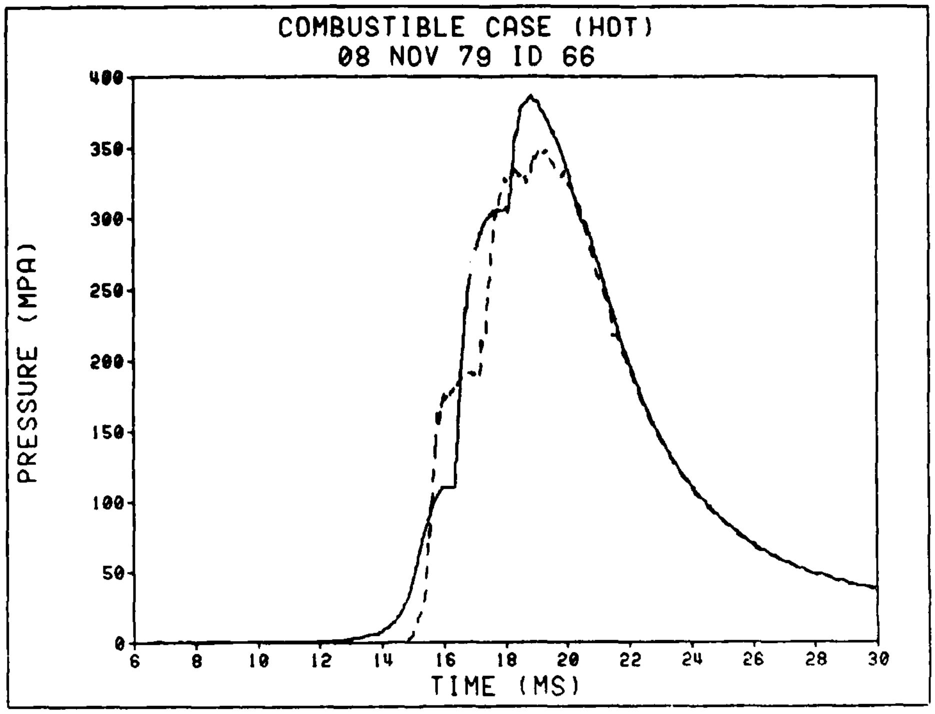
COMBUSTIBLE CASE (HOT)
25 OCT 79 ID 57
PRESSURE DIFFERENCE (MPA)
TIME (MS)

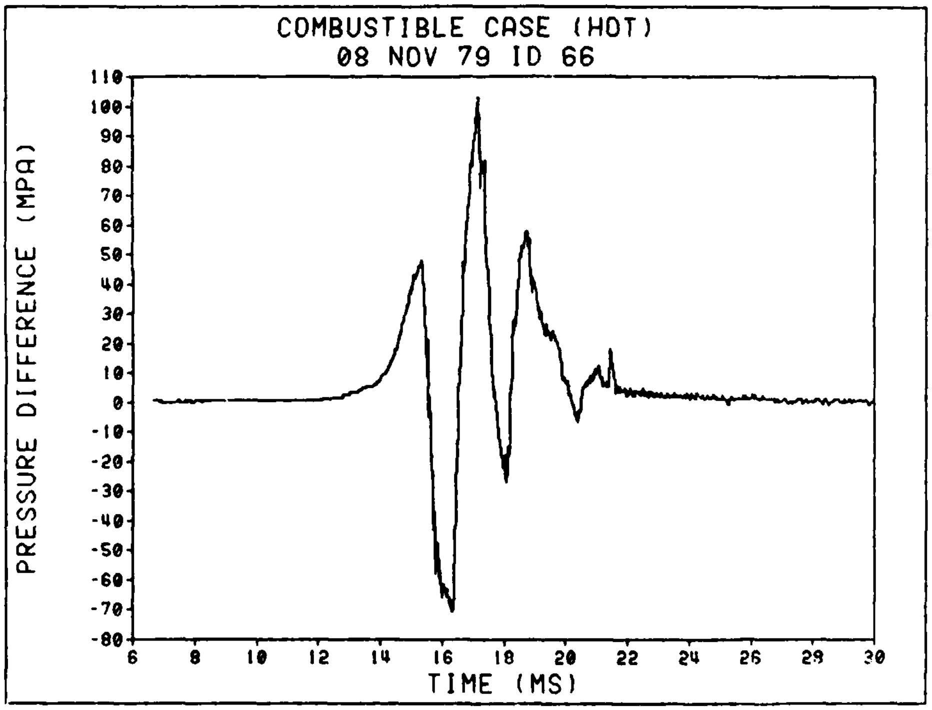

COMBUSTIBLE CASE (HOT)
25OCT79 ID 58
PRESSURE (MPA)
TIME (MS)


COMBUSTIBLE CASE (HOT)
25OCT79 ID 58
PRESSURE DIFFERENCE (MPA)
TIME (MS)


COMBUSTIBLE CASE (HOT)
25 OCT 79 ID 59
PRESSURE (MPA)
TIME (MS)


COMBUSTIBLE CASE (HOT)
25 OCT 79 ID 59
PRESSURE DIFFERENCE (MPA)
TIME (MS)


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 66
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
6
8
10
12
14
16
18
20
22
24
26
28
30


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 66
PRESSURE DIFFERENCE (MPA)
TIME (MS)
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
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-70
-80
6
8
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16
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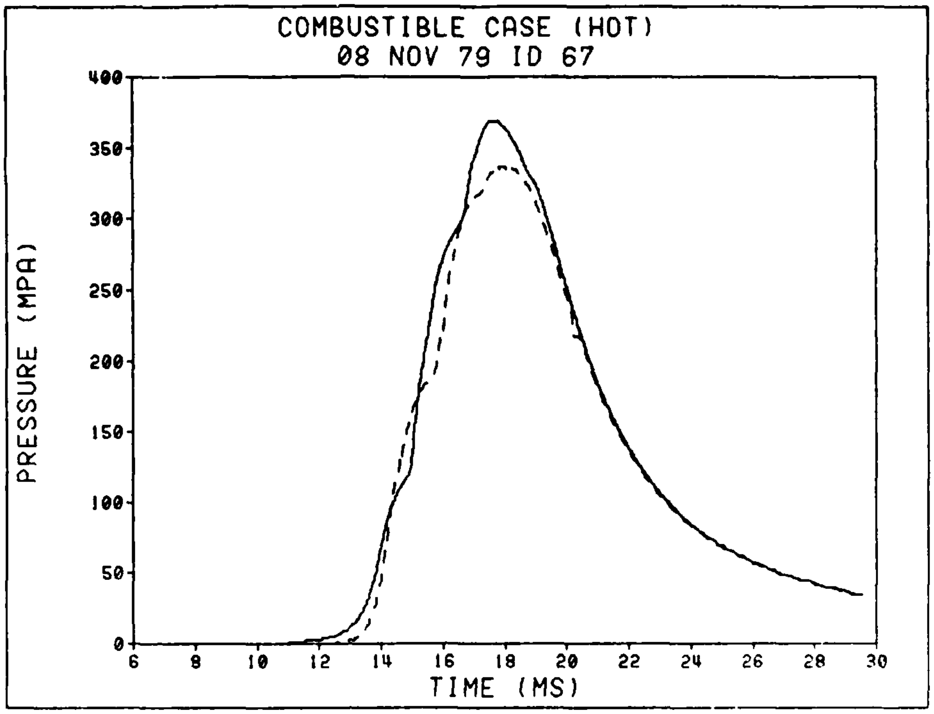
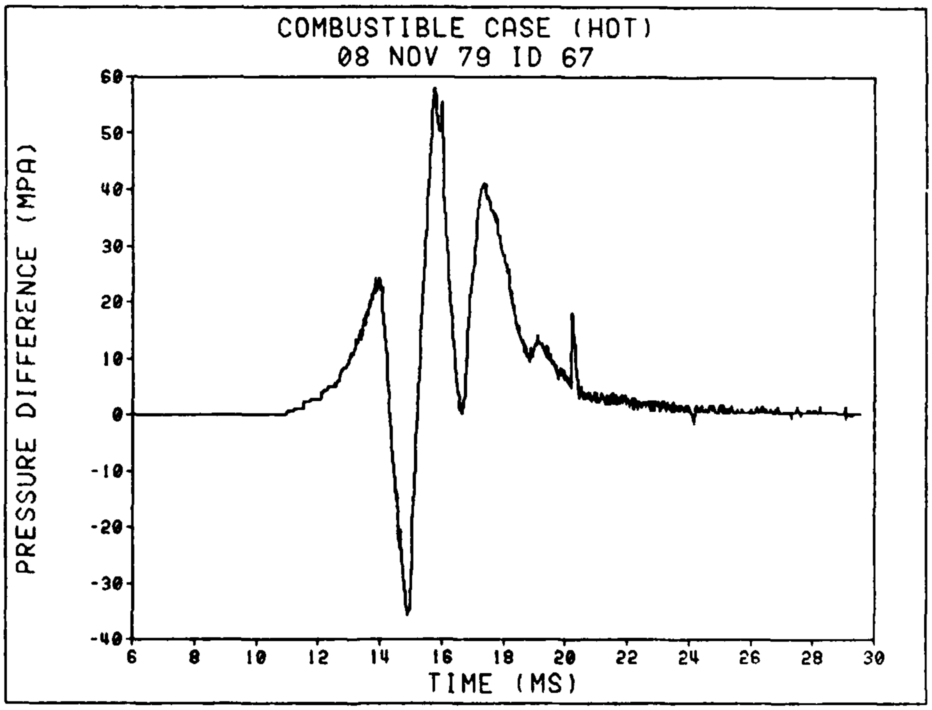
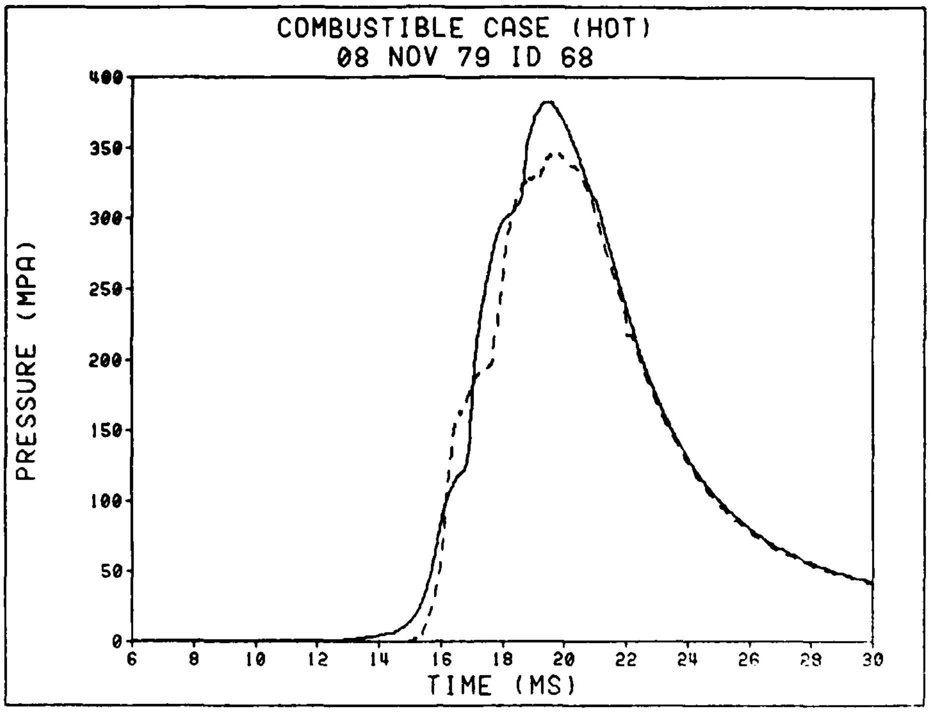
28
30


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 67
PRESSURE (MPA)
TIME (MS)


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 67
PRESSURE DIFFERENCE (MPA)
TIME (MS)


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 68
PRESSURE (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
6
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10
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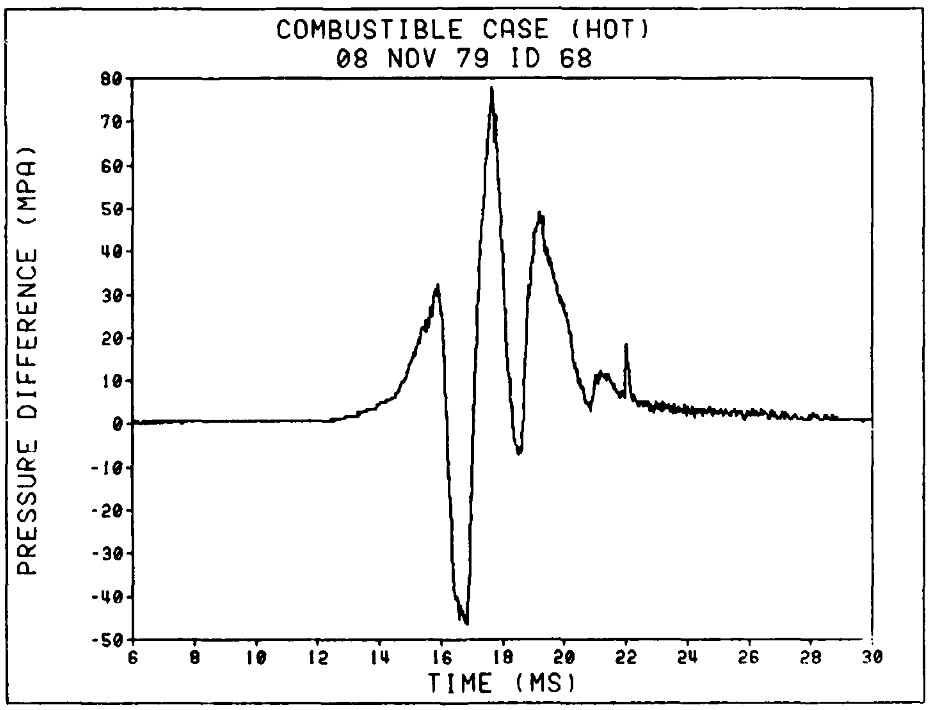
22
24
26
28
30


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 68
PRESSURE DIFFERENCE (MPA)
TIME (MS)
80
70
60
50
40
30
20
10
0
-10
-20
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-40
-50
6
8
10
12
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16
18
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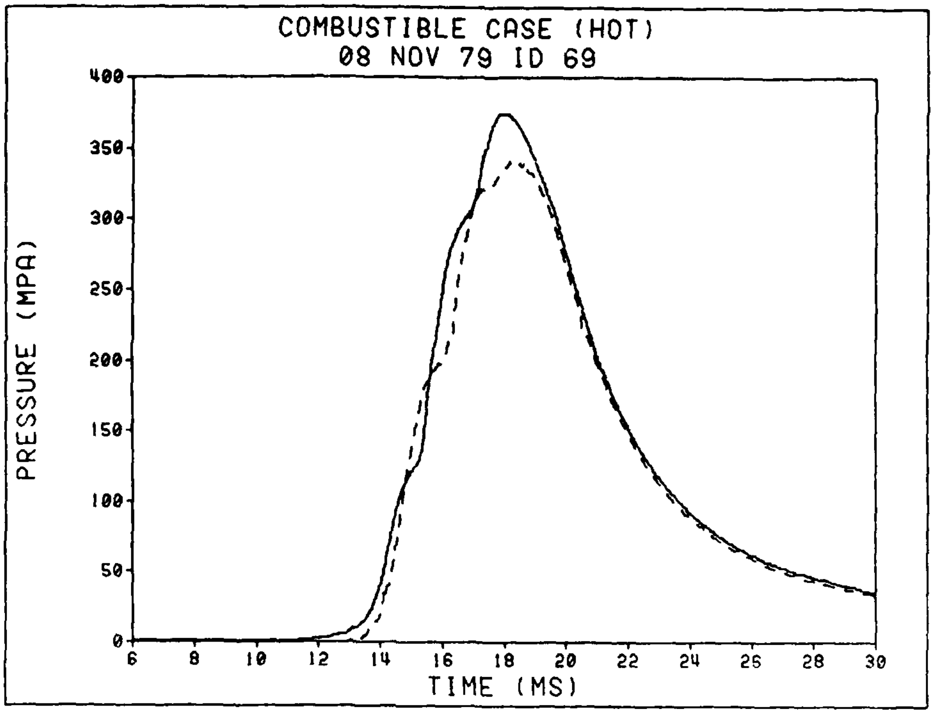
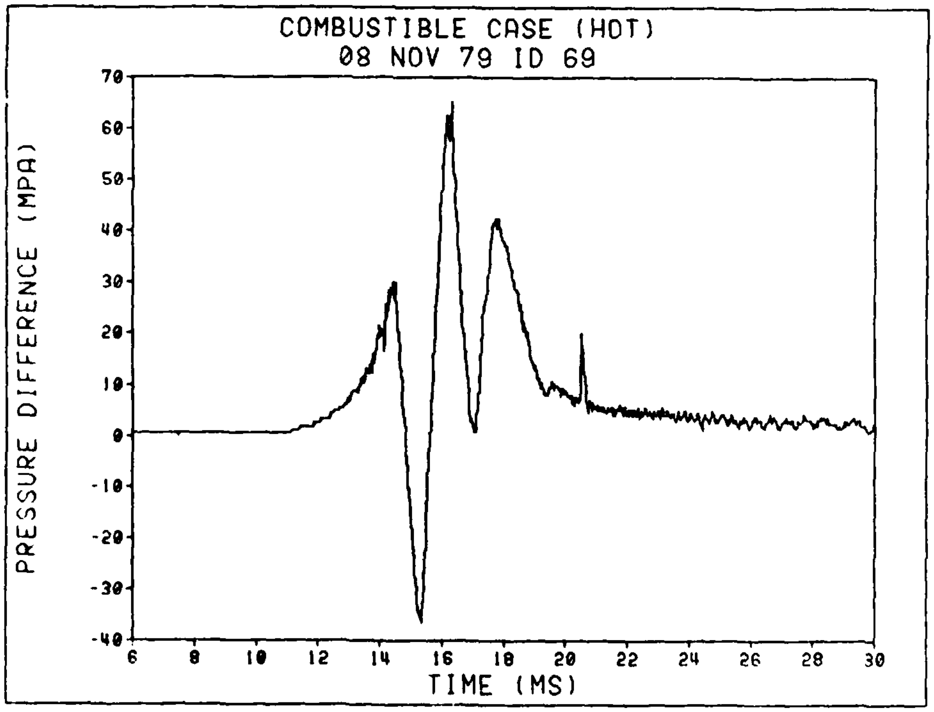
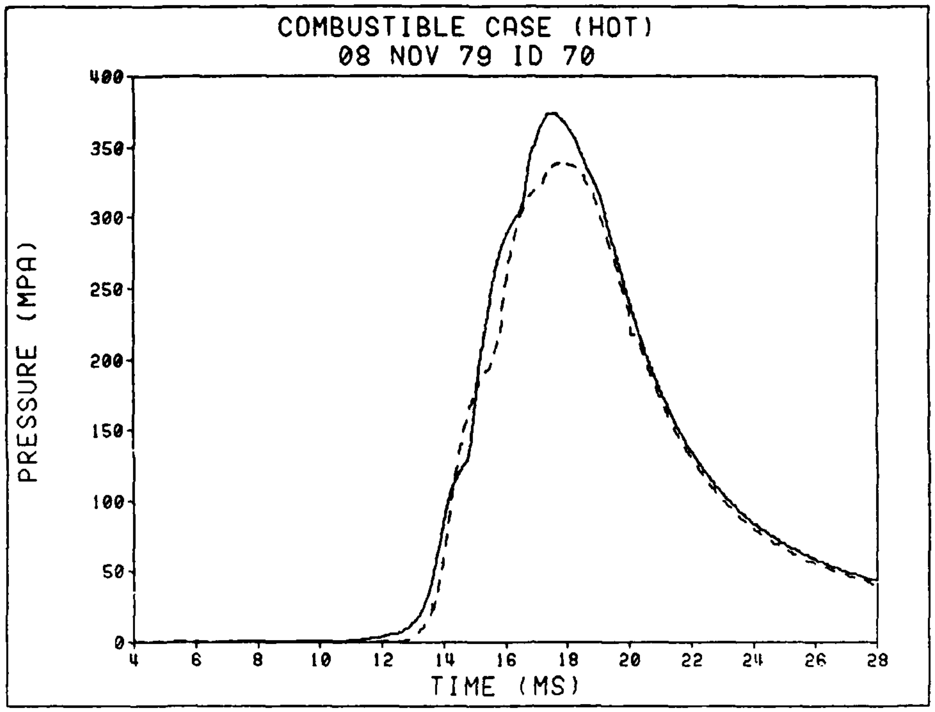
22
24
26
28
30

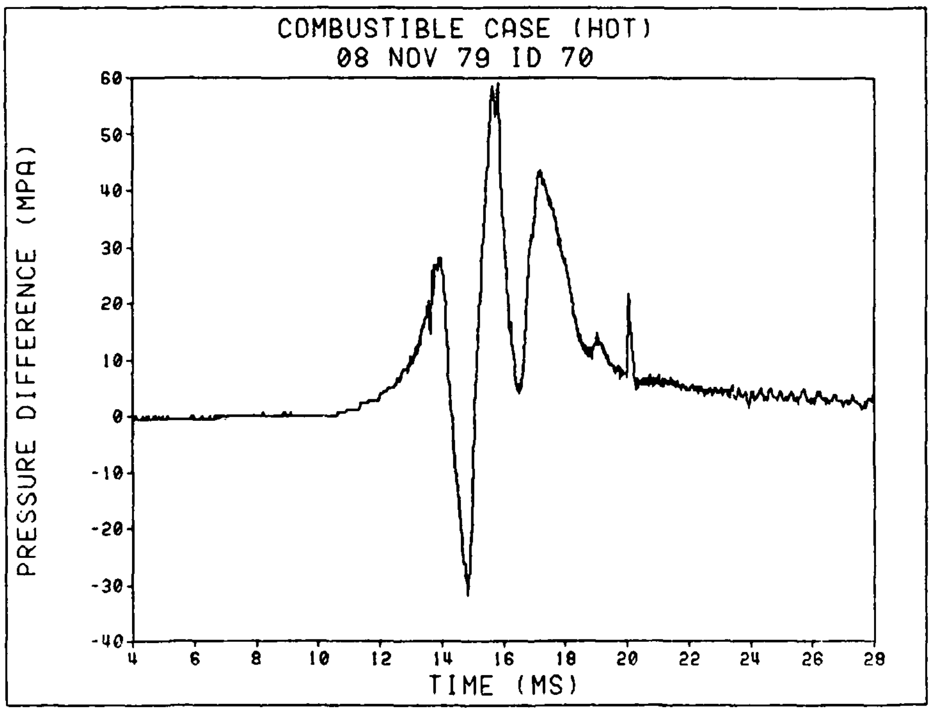


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 69
PRESSURE (MPA)
400
350
300
250
200
150
100
50
0
6
8
10
12
14
16
18
20
22
24
26
28
30
TIME (MS)



COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 69
PRESSURE DIFFERENCE (MPA)
70
60
50
40
30
20
10
0
-10
-20
-30
-40
6
8
10
12
14
16
18
20
22
24
26
28
30
TIME (MS)


COMBUSTIBLE CASE (HOT)
08 NOV 79 ID 70
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
4
6
8
10
12
14
16
18
20
22
24
26
28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-10
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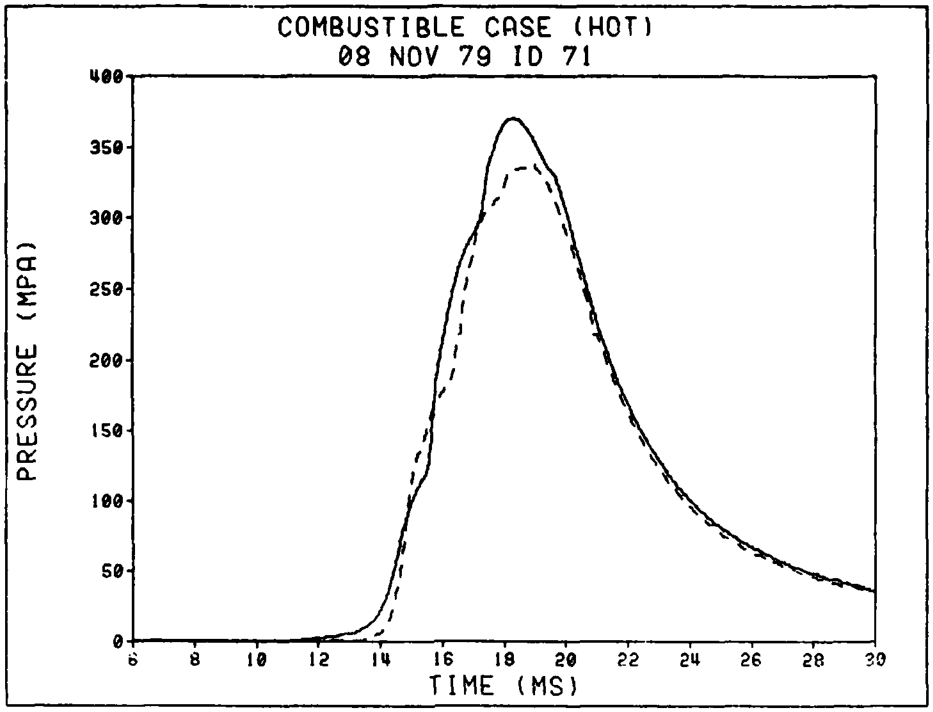
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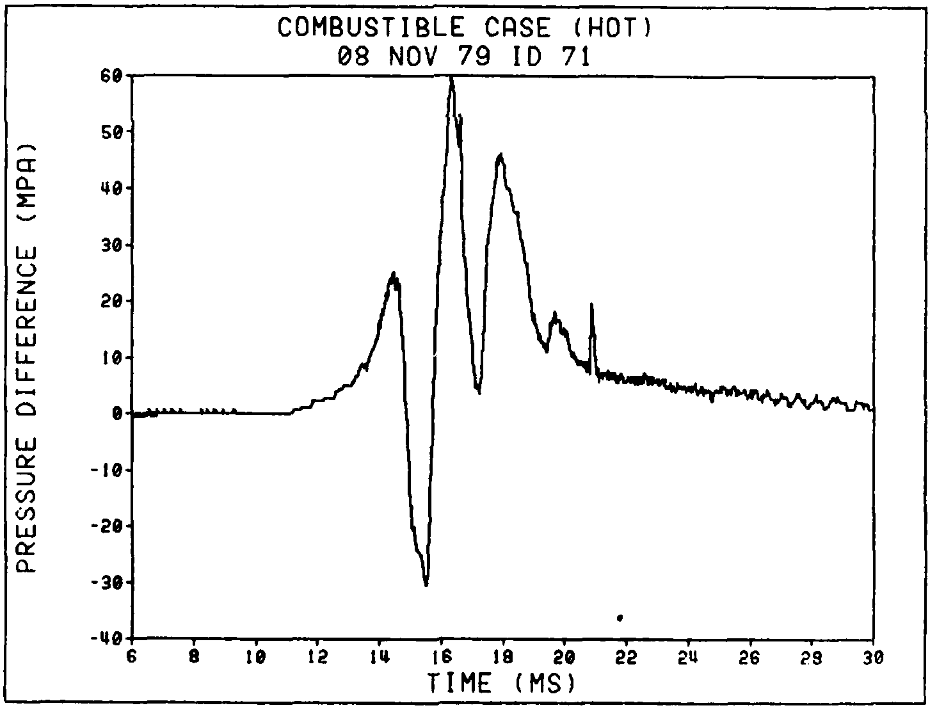
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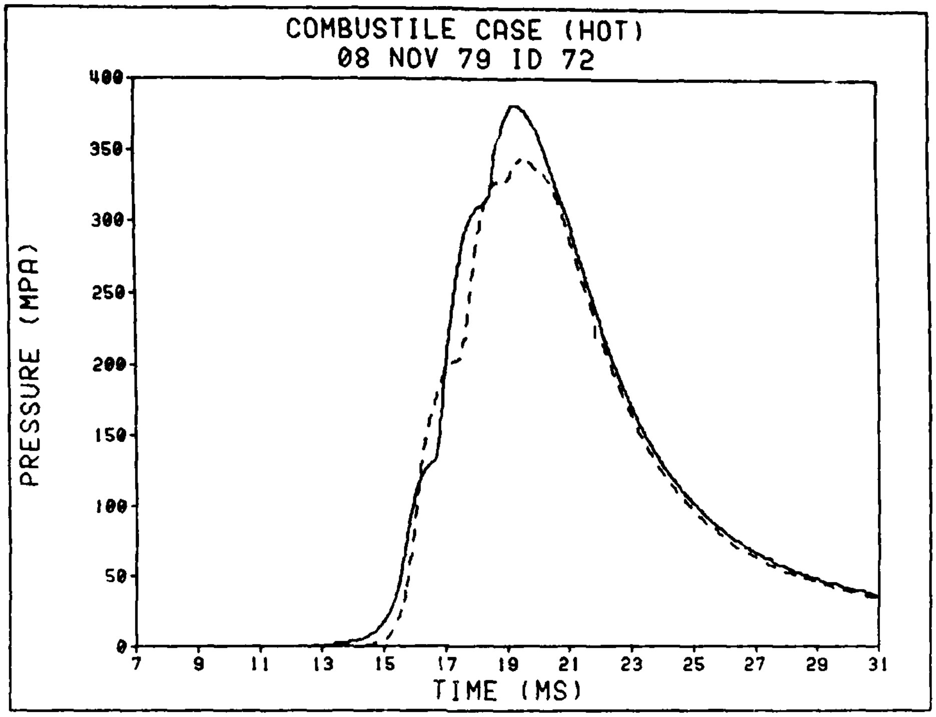
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TIME (MS)
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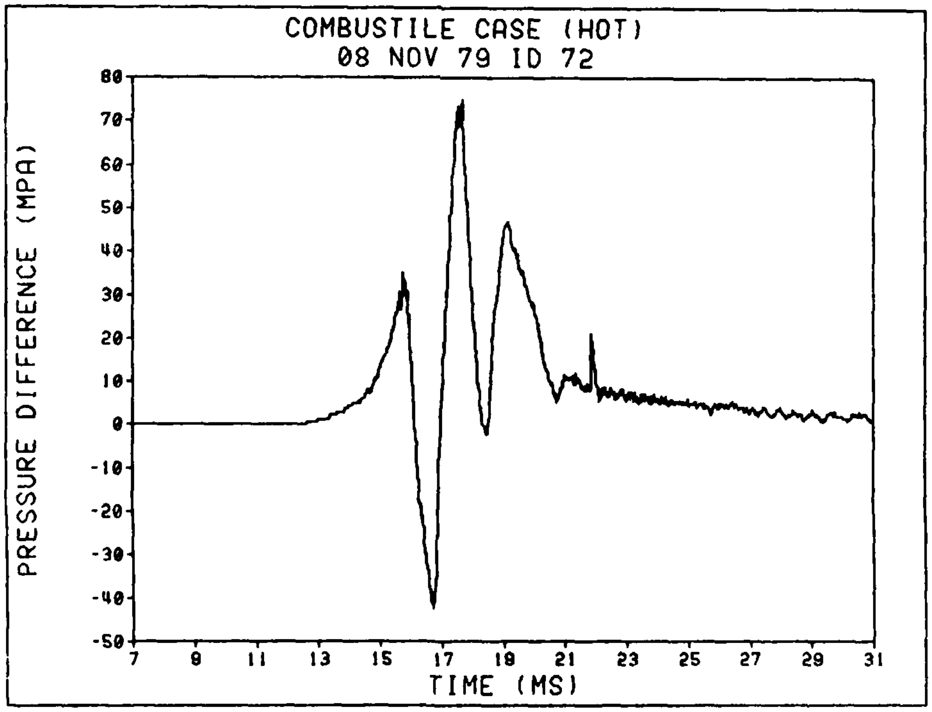
COMBUSTILE CASE (HOT)
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PRESSURE DIFFERENCE (MPA)
TIME (MS)
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